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PRELIMINARY DESIGN OF A COMPREHENSIVE WASTE OIL PROCESSING FACILITY

MARYLAND ENVIRONMENTAL SERVICE

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Garth D. Gumtz and Edward J. Martin

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Blvd., Rockville, Maryland 20852
Under contract to
Maryland Environmental Service, Tawes Office Bldg.,
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A preliminary design is presented for a comprehensive waste oil recovery and disposal facility for the State of Maryland. The base for this design was an annual state-wide waste oil generation of 22,000,000 gallons which includes all known waste oil sources. With a 90 percent stream factor, feed to the plant is 66,000 gallons per day.

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PRELIMINARY DESIGN OF A COMPREHENSIVE WASTE OIL PROCESSING FACILITY

By

Garth D. Gumtz
Edward J. Martin
Environmental Quality Systems, Inc.
Rockville, Maryland 20852

Grant No. S-800650
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Project Officer

Peter B. Lederman
Industrial Waste Treatment Research Laboratory
Edison, New Jersey 08817

NATIONAL ENVIRONMENTAL RESEARCH CENTER
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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The preliminary design presented in this report is a supplement to "State of Maryland Waste Oil Recovery and Reuse Program" (EPA-670/2-74-013 January 1974). The design volume presented is based on the 22,000,000 gallons of waste oil projected for the State of Maryland in 1975. The reports present preliminary prototype plans and designs for estimating the quantities generated, and the collection and recycling of waste oil in an environmentally acceptable manner for the State of Maryland. The research presented will be useful for other states in the assessment and implementation of environmentally sound waste oil recycling and disposal plans.

A. W. Breidenbach, Ph.D
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

A preliminary design was performed for a comprehensive waste oil recovery and disposal facility for the State of Maryland. The base for this design was an annual state-wide waste oil generation of 22,000,000 gallons which includes all known waste oil sources. With a 90 percent stream factor, feed to the plant is 66,000 gallons per day.

The facility contains two major sections: 1) tank farm and 2) process plant. The tank farm is, in turn, composed of three major subsections: 1) receiving, 2) primary waste oil storage, and 3) product tankage. The comprehensive process plant has been designed to accept a wide range of waste oil types (crankcase, hydraulic, transformer, edible, etc.) and, potentially, provide multiple product oils (fuel, re-refined industrial, etc.). For this, it contains three major subsections: 1) adsorbent treatment, 2) solvent extraction, and 3) incineration. Basic processing will involve, in order, reagent addition and settling, flash distillation, adsorbent treatment followed by filtration, or solvent extraction followed by solvent recovery.

Capital cost for this full-scale comprehensive facility is estimated at \$5,700,000. Excluding collection costs, overall system management, and major research and development, annual operating costs are estimated at about \$2,331,000. Approximately 16,000,000 gallons of fuel oils and 500,000 gallons of lube oil base stock will be produced by this facility each year. Waste products generated include heavy metal particulates and calcium halides and sulfate.

This report was submitted in partial fulfillment of Grant Number S-800650 under the sponsorship of the Office of Research and Development, Environmental Protection Agency. The work was completed as of October 1973.

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SECTION I

CONCLUSIONS AND RECOMMENDATIONS

A preliminary design has been completed for a waste oil recovery process plant intended to receive all of Maryland's waste oils for the year 1975. The proposed facility's yearly capacity was estimated to be 22,000,000 gallons based on extrapolation of existing data; this design volume for waste oil is in good agreement with the results of the waste oil survey presented in the main report for this project.

The proposed plant is comprehensive in nature; that is, it has been conceived to provide processing for a wide range of waste oils (essentially all those generated in the State of Maryland), and to produce, potentially, a wide range of product oils. Compared to existing re-refining practice, this approach to processing waste oils is a radical innovation and provides the only practicable means to resolving Maryland's waste oil processing problem in entirety. As might be surmised, the investigation which led to proposing such a facility involved extensive analysis and evaluation.

Considerable attention was also paid during the preliminary design effort to pollution abatement and control at the processing facility; the result was extensive incineration and waste recovery capabilities as well as extensive process flexibility. The basic re-refining process plant subsections involve state-of-the-art technology, adsorbent treatment and solvent extraction, which are in line with existing practice. Flowsheets, capital and operating cost estimates, mass and energy balances, and basic equipment specifications have been prepared for the proposed facility. The paragraphs below serve to highlight the results of the preliminary design study.

The following conclusions were reached based on the results of the preliminary design study:

1. Existing technology can provide a number of potential alternatives for waste oil processing in the State of Maryland.

2. The process plant selected for the overall Waste Oil Recovery and Reuse Program (WORRP) involves the following basic processing operations: adsorbent treatment, solvent extraction, and incineration. The plant as presently conceived would be capable of receiving 22,000,000 gallons of waste oil per year or 66,000 gallons per stream-day. This is all the waste oil generated in the State of Maryland (including waste crankcase, industrial, and all other oils) as projected for 1975.

3. The flexibility of the proposed facility is intended to provide for processing of the widest possible range of waste oils. This contrasts to existing re-refiners who handle only selected feedstocks. The MES plant will receive, treat, and dispose of materials as wide in range as tank bottoms, waste edible oils and fats, halogenated oils, crankcase oils, and others.

4. Although fuel oil has been designated as the primary product from the facility, in principle, products as diverse as the feedstocks which the plant receives can be produced. Production of the less expensive (fuel oil) products does, however, minimize the initial capital investment as well as the problems with marketing and sales.

5. Extensive tankage will be necessary to support such a processing facility. Although most of the tankage volume will be devoted to product storage, the largest number of tanks and the largest portion of tankage costs will be due to receiving facilities and primary waste oil storage.

6. Preliminary estimates are that 23 percent of incoming waste oils will have to go directly to ultimate disposal. These are, substantially, oils which are presently being disposed of in environmentally unacceptable ways: road oiling, direct burning, dumping, and others.

7. The waste oil feed not sent directly to ultimate disposal (77 percent of the total) will be processed to yield saleable products. Approximately 13,500,000 gallons of waste oil will be recovered per year in the plant's basic fuel oil configuration; this represents a process yield of about 79 percent and will, when cut, result in about 16,000,000 gallons of fuel oils.

8. Overall plant recovery of product oils will be about 61 percent of the total feedstock or 13,500,000 gallons per year. Only a small amount of this total, about 500,000 gallons, will be lubricating oil base stock; the rest will be blended with virgin oil and used for medium and heavy fuel oils: Numbers 4, 5, and 6. This blended oil would be suitable for State institutional use.

9. Total capital cost (first quarter of 1973) for the proposed facility is estimated to be $5,700,000. Of this, $4,050,000 and $1,650,000 are the estimated requirements for the process plant and tank farm, respectively.

10. Of the total capital cost required for the process plant, approximately 34 percent must be allocated to ultimate disposal facilities, that is, to waste incineration, recovery, storage, and disposition.

11. A reduced-scale (first phase) plant, which would perform all of the essential functions of the full-scale facility but at about 1/3 the capacity, would require a capital investment of about $3,060,000.

12. An estimated 22 people would be required to operate the proposed full-scale facility. (These would include personnel for on-site engineering, clerical, maintenance, and analytical services as well as a staff for receiving, tank farm, and process operations.)

13. Preliminary design estimates are that for the full-scale process facility summarized above, operation and maintenance will require about $1,316,000 per year. On the basis of a lease cost for the plant ($958,000 per year), insurance charges ($57,000) and product revenues ($2,558,000), nominal profit is generated before taxes; note that in this case no costs were allocated to waste oil collection since the process plant was considered an entity in its own right.

14. Accepting the assumptions inherent in the preliminary design of this report, implementation could proceed immediately. However, due to the lack of a secure design data base, other preliminary actions are suggested and outlined briefly below.

The following recommendations are made regarding a full-scale waste oil process plant for the State of Maryland:

1. Bench- and pilot-scale studies should be made for ultimate disposal by incineration before final design is initiated; this work should emphasize contaminant recovery and disposition.

2. Additional process studies should be made for both adsorbent and solvent treatment of a variety of waste oils. Activated carbon should be investigated as a potential adsorbent for waste oil processing. These oils should be representative as regards the results of the waste oil survey.

3. Since the technology and economics for the processing facility appear promising based on the preliminary

design work, final design and construction should be possible assuming favorable results from the above two studies.

4. The processing facility should be constructed and operated in stages. The first-phase facility, as presented in this report, should provide a more secure data base for eventual comprehensive, full-scale waste oil recovery and disposal operations by providing data on full-scale waste oil generation and processability.

SECTION II

INTRODUCTION

Approximately 22,000,000 gallons of waste oil will be generated in the State of Maryland in 1975. This report presents the results of the engineering of a processing facility capable of recovering or disposing of all this waste oil. Comprehensive waste oil control, processing and disposal is a difficult and pressing problem which has never before been addressed in detail. For multiple feedstocks, multiple process trains are required for successful, comprehensive processing. Adsorbent treatment, solvent extraction, and incineration process subsections have been included in the proposed MES facility. Incineration is especially critical since it provides a "disposal" path for the dregs of the waste oil market; pollution control (e.g., ultimate waste recovery from stack gases) within this plant subsection is crucial. Classical re-refining practice has not been required in the past to meet strict requirements for water and air pollution control; emphasis has always been on a limited processing capability. The approach considered here, however, is to re-process or ultimately dispose of all types of waste oils.

Not only must a comprehensive waste oil processing facility handle all of Maryland's waste oils, but it should also produce products having reuse potential. Since the economics for fuel oil production are not inferior to those for production of other oil products, and since the State has fuel oil requirements of the same order of magnitude as statewide waste oil generation, a fuel oil producing facility has been specified, at least for the first several years of operation. In this sense, Maryland provides an ideal base for comprehensive waste oil recovery operations. Similarly, users in Maryland generate a wide range of waste oils so that a realistic assessment of the problems associated with comprehensive waste oil control and disposal must be made. Such a facility will also require tankage sufficient to ensure appropriate segregation of waste oil types; this factor is covered in detail in the main body of this report.

Besides accepting a wide range of feedstocks (from waste edible and tank bottom oils to waste crankcase oils), a comprehensive process plant should also be capable of producing a wide range of products. This calls for judicious process selection. Such a requirement must be accompanied by associated requirements for pollution control and sound environmental quality control practice. This is especially critical for a program possessing the environmental implications of waste oil recovery. Therefore, during the development of the preliminary design presented in the following sections, substantial effort was directed to pollution control requirements.

Comprehensive waste oil recovery and disposal deviates in a number of essential ways from standard refining practice and, in fact, relates in a fashion to development of industrial or municipal waste treatment systems. Waste oil quantity and quality varies significantly; collection may be sporadic, and processing requirements may vary on a day-to-day basis. Product demand and feedstock supply do not necessarily track very closely. Furthermore, ultimate waste disposal is a major (or possibly the major) problem in the waste oil re-refining industry. The scale of processing is also much smaller in the re-refining industry compared to the refining industry: hundreds of barrels per day versus thousands or tens of thousands. Also, the re-refining industry receives the contaminated, finished products of the refining industry, not virgin crude oils.

The preliminary design analysis presented in this report represents the first attempt to provide a process plant for all the waste oils from a large, heterogeneous geographic area. The general approach is in consonance with accepted practice in the waste oil re-refining, the chemical process, and the waste treatment and disposal industries. The preliminary design is outlined as follows:

1. Waste oil generation estimates and process selection;
2. Determination of receiving and feedstock tankage requirements, and design of the basic tank farm;
3. Selection of process equipment, flowsheet preparation, instrumentation requirements, and mass and energy balances;
4. Product tankage requirements;
5. Estimation of land requirements;
6. Preparation of capital cost estimates; and
7. Operation and maintenance cost estimates including plant staffing.

This report contains considerations of the above factors for both full-scale and first-phase processing facilities.

SECTION III

DESIGN BASE

Preliminary design of a comprehensive waste oil processing facility depends initially upon 1) estimates of waste oil generation and 2) specification of definite process unit operations for recovery and disposal. The following two subsections cover these subjects in detail and subsequently serve as a base for the detailed preliminary design which follows.

WASTE OIL/FEEDSTOCK GENERATION

The initial step in the preliminary design was determination of the supply of feedstock. Since the results of the waste oil surveys were not available during the early course of the preliminary design work, feedstock waste oil quantities and quality for the processing facility had to be estimated from other sources. The primary source was, of course, the state-of-the-art report prepared earlier in the project. Table 1 presents the design quantities which were used as well as analogous quantities from the waste oil survey. These values have been projected to 1975 for design purposes and refer to very broad waste oil categories. Although the gross quantities of oil according to the two sets of data agree very well, this must be fortuitous since the individual quantities vary significantly (especially for the waste industrial oils). As noted in the table, preliminary estimates are that 5 million of the 22 million gallons generated will be non-recoverable, that is, will require incineration or disposal by other than reprocessing. Such gross waste oil quantities are not very suitable for preliminary design purposes. The variable waste oils refer to those which waste oil haulers presently collect on a highly irregular basis. The breakdown into waste crankcase, fuel, and industrial oil subcategories is for design purposes only and was determined based on subjective impressions by the actual waste oil haulers. Since, due primarily to the state-of-the-art review, other waste oil sources were known to exist, such a category was included for preliminary design purposes at 10 percent of the total quantity of crankcase, industrial, and variable waste oils; again, the subcategorical breakdowns are for preliminary design purposes.

Although the 22,000,000 gallon-per-year waste oil feed was a base for the preliminary design effort, smaller and larger facilities were also considered. The "small base plant" detailed in this report was specified by requiring every basic unit process of and equipment selection from the larger plant. The result is a facility with an estimated capacity of 10,000,000 gallons per year. To ascertain the effect of receiving more processable waste oil at the MES plant, a 30,000,000-gallon-per-year facility was also considered briefly; the additional 8,000,000 gallons

Table 1. 1975 PROJECTED WASTE OILS

Category	1975 Design Annual Quantity (gal)	1975 Design Stream-Day Flow (gal)	1975 Survey Projected Quantity (gal)
Waste Crankcase Oils	11.1×10^6	33,300	9.6×10^6
Waste Industrial Oils	4.9×10^6	14,700	6.0×10^6
Variable Waste Oils[a]:			
Crankcase	1.0×10^6	3,000	6.6×10^6[b]
Fuel	2.0×10^6	6,000	
Industrial	1.0×10^6	3,000	
Other Waste Oils[c]:			
Industrial	1.0×10^6	3,000	
Edible	0.5×10^6	1,500	
Miscellaneous	0.5×10^6	1,500	
TOTALS	22.0×10^6[d]	66,000	22.2×10^6

(a) Total based on confidential private communications; breakdown estimate based on possible source information.

(b) Includes both variable and other waste oils.

(c) Estimated at about 10 percent of the above waste oils in total; based on confidential interviews with generators and handlers of waste oils.

(d) Includes approximately 5.0×10^6 gallons per year of non-recoverable waste oils.

per year were assumed imported to Maryland and amenable to standard processing procedures. Since estimates for this larger plant were used only for general economic comparisons, the results are presented in the main report for the project.

PROCESS SELECTION -- RE-REFINING

The literature, existing re-refining operations and ongoing research and development provided a host of unit operations with potential for the MES waste oil recovery facility. However, many technical approaches were considered only briefly because they had not progressed beyond a bench-scale and, therefore, were not amenable to the necessary immediate implementation. Those unit processes which were deemed potentially useful are presented in Table 2. The basic function of each process is briefly described and the "product" oil resulting from each is delineated. Note that these unit processes aim at recovery, not ultimate disposal which will be considered later in this Section. Inclusion of a unit operation in the tabulation is based only on general applicability to re-refining as well as some practical experience with same by others.

In light of present technology, a number of these particular unit operations must be combined into appropriate process trains to yield a technique(s) which will allow the recovery of product from waste oils. Not all the unit operations need be included in a given process plant since some perform similar functions.

Appendix A contains a listing and brief description of the general design criteria used in selecting unit processes. The following paragraphs contain the rationales for unit process selection for the MES facility. Selection was limited to those processes listed in Table 2.

Settling was selected for the WORRP facility based primarily on proven performance, low capital cost, ease of implementation and wide applicability for waste oils. It also uses otherwise necessary tankage for processing and is widely flexible in terms of treatment times. Settling would be used as a first treatment step in most re-refining schemes. Its major disadvantage is lack of product purity; that is, in its own right, settling does not usually result in a product suitable for use as a fuel oil, let alone a lubricating oil or lube base stock. Furthermore, very small or neutral density particles do not separate effectively with this technique. Long settling times (on the order of weeks) or heating may also be required to promote separation.

Centrifugation has not been included in the facility design due to high capital, operating and maintenance costs as well as lack of proven performance in the waste oil processing field. It is also not straightforwardly applicable to multi-phase separations and may require heating or oil dilution. Throughputs and residence times are usually not adjustable over a wide range of feed characteristics. With settling available as a

Table 2. POTENTIAL WASTE OIL RE-REFINING UNIT PROCESSES

Unit Process	Function	Product
A) Settling	Removal of gross water, coarse solids and other materials heavier than the oil	"Clarified" oil for further processing
B) Centrifugation	Removal of water, solids, and other materials heavier than the oil	"Clarified" oil for further processing
C) Flash Distillation	Removal of light ends, naphtha, and water	Naphthas and water-free oil product or oil for further processing
D) Chemical Treatment (Caustic Wash, Demulsification, Oxidation, and Agglomeration)	Removal of acidic compounds, additives and contaminants stabilized in solution and suspension	Purified oil for further processing
E) Sulfuric Acid Treatment	Removal of additives and contaminants stabilized in solution and suspension	Purified oil for further processing
F) Fractionation	Separation of heavy contaminants plus splitting of oil into various fractions	Various oil cuts for further processing including stabilization
G) Hydrofining	Reduction of nitrogen, sulfur and oxygen contaminants with hydrogen	Purified base lube oil stock
H) Solvent Extraction	Selective extraction of oil contaminants	Fuel oil stock or refined base lube stock
I) Adsorbent Treatment	Adsorption of metallic, sulfuretted, chlorinated and other additives plus odor and color bodies	Purified oil slurried with contaminated adsorbent
J) Filtration	Removes suspended and settleable solids from oil	Oil or base oil stock

more straightforward option, it is suggested (even though centrifugation may give somewhat better separations, require less land area, and permit more rapid processing) that centrifugation not be considered until more favorable development work or data is forthcoming.

Flash distillation is required for the proposed MES facility as well as most other processing schemes. Given existing technology, it provides the most straightforward manner for removing light hydrocarbon contaminants and residual water from waste oil feedstocks. The performance of this unit process has been proven in the existing re-refining industry, and capital and operating costs are reasonable. In general, however, product purity is such that direct use is not recommended, and energy requirements can be very significant. Heaters for flash distillation of waste oil will require special design and more frequent maintenance than those used in general refinery practice.

Although existing practice has demonstrated that sulfuric acid treatment of waste oils can lead to excellent product quality, relatively low process yields and almost intractable residue problems lead to a firm recommendation against its use in the proposed MES facility. Application is generally limited to crankcase or similar oils. Acid treatment can also require a sludge disposal program which is much more extensive than that for the processing itself. Again, although performance has been demonstrated, rapid implementation is possible, and capital and operating costs are low, sulfuric acid treatment is not recommended.

Chemical treatment is a viable alternative to sulfuric acid treatment for the production of fuel oils. Although demulsifiers, flocculating aids, contaminant oxidizers and conditioning reagents (e.g., caustics) are available commercially, chemical treatment of waste oils has not yet been demonstrated on a large scale. However, low capital and operating costs, high product yields, potential wide application, low energy requirements, and, especially, low residue production make chemical treatment an attractive choice for a waste oil processing facility involved primarily in fuel oil production. Also, the necessary process hardware is the same as for settling and, as compared to acid treatment, is applicable to a wider range of waste oil types.

Vacuum fractionation is a proven unit process in the waste oil re-refining industry. However, problems with high capital cost, lack of applicability to waste oils over a wide enough range, maintenance, and large amounts of residue or still bottoms weighed against including it in the MES facility design at the present time. This unit process has a potential for production of a range of products and could be implemented quickly. Problems with direct fired heating are similar to those for flash distillation, while operating temperatures are significantly higher. For the production of lubricating oils, vacuum fractionation is extremely promising based on eventually following it with an appropriate finishing process (See the following paragraph). In a comprehensive facility it is necessary to process waste oils containing large amounts of liquid additives (e.g., chlorinated oils or silicones). On this basis, vacuum distillation was not selected for the MES preliminary design.

Since it aims primarily at finished lube oil production, involves high capital cost, and has not been demonstrated in actual re-refining operations, hydrofining was not included in the preliminary design. This process requires special catalysts which can be poisoned by many of the contaminants common to waste oils. Depending upon contamination levels, large amounts of hydrogen may also be required; of course, the required hydrogen plant represents a major additional capital cost. Hydrofining is also a relatively high temperature and pressure process and can depend critically on the nature of the feed waste oils. However, all factors considered, this unit process still has great promise and, combined with pretreatment such as vacuum distillation, could eventually lead to the production of high quality lube base stocks from waste (primarily crankcase) oils. For fuel oil production, however, hydrofining was deemed too costly and perhaps too advanced a processing technique. Development efforts in the months and years ahead could alter this view significantly.

Like vacuum fractionation, solvent extraction has been demonstrated in full-scale operations (although not specifically for fuel oil production). Use of pentane, heptane, or solvent grade naphtha rather than propane should be suitable for fuels. Solvent may actually be produced in a waste oil processing facility by the flash distillation of the feedstock. Since a comprehensive waste oil processing facility will have to deal with oils containing large quantities of bulk liquid additives, a process like solvent extraction which can partition these additives from the recoverable oils is desirable. Since no other alternative for this operation was available within the existing technology, solvent extraction was selected for preliminary design purposes. Note that, in general, solvent can be selected to suit a particular feedstock. Capital and operating costs can, however, be high for solvent extraction relative to a unit process like distillation. Given that solvent is successfully recovered, however, operating costs can be kept reasonable. Product yield may also be less than that used for preliminary design purposes; relatedly, separation of extract and raffinate phases can be difficult when their densities are similar and surface properties compatible. Energy requirements for solvent extraction are high relative to flash distillation due to the necessity of solvent recovery. Rather sophisticated process and quality control may be required for efficient processing of a wide variety of waste oils. However, without a viable alternative, solvent extraction has still been included in the preliminary design.

Although adsorbent treatment (given that a destructible adsorbent like activated carbon cannot be used) results in a residue production problem, other factors relating to this unit process are favorable enough to weigh in its favor. For instance, the performance of adsorbent (clay) treatment has been widely demonstrated, capital costs are low and implementation should be very straightforward. Adsorbent treatment can provide excellent polishing of an oil product, thereby removing trace contaminants or odor and color bodies. Furthermore, used adsorbent, if incinerated properly, presents minimal landfill disposal problems; the oily sludge accompanying the adsorbent is the real pollution problem and, if burned completely, leaves no significant contaminants, according to present industry practice. Other disadvantages are requirements for pretreatment and subsequent filtration as well as heater problems similar to those for flash distillation.

Filtration is included in the preliminary design to remove not only spent adsorbent but also flocculated/agglomerated contaminants from the product fuel oil. Rotary vacuum filters have been demonstrated for large-scale, continuous operation in the waste oil processing industry. This unit process can be applied to a wide range of feedstocks. Although capital cost, operating cost and residue production are high, filtration must necessarily be included in the preliminary design, given the solids which must be removed to yield an acceptable product oil. It should be noted that some colloidal suspensions and emulsions are not readily amenable to filtration.

Appendix B contains diagrammatic evaluations of the various unit processes which have been outlined above; included is a "typical" process alternatives rating matrix.

In summarizing the paragraphs on unit process selection, fuel oil production by the proposed facility must be re-emphasized. If the primary aim were to produce lubricating oils, other processes could be more advantageous. For instance, sulfuric acid treatment would be more attractive, and disposal of acid sludge wastes would have to be looked at in more detail. In a related fashion, propane extraction with subsequently reduced acid/clay treatment would have to be more carefully considered.

Perhaps the most promising of the newer approaches to lube oil production from waste (primarily crankcase) oils is a combination of settling and vacuum fractionation followed by hydrofining. The former two unit processes have been proved in the existing re-refining industry although fractionation does not, in and of itself, usually lead to a suitable lube oil product; this is due primarily to problems with instability

As opposed to, for instance, hydrocracking, hydrofining is a mild hydrogen treatment. That is, temperatures and pressures are relatively low, and the main effects are those of a mild hydrogenation. The latter serves to eliminate the unsaturated hydrocarbons which are the primary cause of lube oil instability (through polymerization, oxidation, etc.). Since a catalyst is required for hydrofining, poisoning could be a problem, especially when processing waste oils. However, very recent studies performed for the National Oil Recovery Corporation have indicated that poisoning is not as serious a concern as had been feared. If appropriate compounds are carried over from vacuum fractionation, materials like hydrogen sulfide, water metallics and carbonaceous residues could be generated; however, the mild conditions of hydrofining weigh against the formation of large amounts of such materials although traces will no doubt have to be dealt with.

High capital and operating costs for both hydrofining and the associated hydrogen production or supply must be carefully considered. If an easy market exists for lube oil products or base stock, production of same can be economically advantageous. This was not, however, the case for the State of Maryland. Waste oil generation is of the same order as total state-wide lube oil consumption; that is, State Government institutions could not utilize a major portion of the potential lube oil product, and sale to or through private industry would represent a significant market penetration. Marketing costs would, no doubt, be prohibitive under these circumstances. Finally, the process combination, settling/vacuum fractionation/hydrofining, has considerable potential for the production of lube oil base stock from waste oils; it should become of more importance in the months and years ahead as development work continues. However, given the requirements for an MES facility based on existing technology plus the problems of comprehensive intrastate product marketing, hydrofining was not included in the preliminary design of the MES facility.

The process evaluation analysis led to the selection of the following for inclusion in the preliminary design of an MES waste oil processing facility:

1. Chemical Treatment
2. Settling
3. Flash Distillation
4. Adsorbent Treatment
5. Solvent Extraction
6. Filtration

Chemical treatment is presently under development and being used in a limited way; minimal effort should be required, with the assistance of materials and hardware suppliers, in providing a treatment scheme(s) with direct application to a range of waste oils. Settling, stripping, and filtration are almost immediately applicable for use on any waste oil since they are state-of-the-art techniques across the existing rerefining industry. Adsorbent treatment is of a similar nature as long as clay is the adsorbent material; due to problems with ultimate disposal and regeneration of spent clay, other adsorbents (e.g., activated carbon) should be looked at carefully before a final design is committed irrevocably to its use. Of the unit operations selected, solvent extraction is certainly the most speculative. However, solvents like pentane and naphtha are used routinely in waste oil laboratory analyses for insolubles; and propane is being used in full-scale operations. Therefore, at least for the production of fuel oils, solvents are available which can successfully partition contaminants.

Each unit process removes contaminants of a certain sort; these contaminants are basically as follows:

1. Gross water, coarse solids, and other materials heavier than oil, i.e., BS&W or settleable materials;

2. Light ends, naphtha and water, i.e., relatively volatile materials;

3. Acidic compounds, additives and contaminants stabilized in solution and suspension (includes nitrogen, sulfur, oxygen, and metal-containing organic compounds);

4. Odor and color bodies; and

5. Suspended and colloidal solids.

Since in a general waste oil re-refining scheme each of the above contaminants must be addressed, no single unit operation can provide complete processing. Selection of settling for a process plant covers the first contaminant category. Stripping covers the second; adsorbent treatment the third (in limited quantities) and fourth; solvent extraction the third (in larger quantities); and filtration the fifth. Selection of the chemical treatment serves to enhance the removal of the first, third and fifth contaminant categories. Table 3 lists contaminants and relevant removal techniques in more detail.

The proposed waste oil re-refining process, therefore, involves two basic process trains:

1. Chemical treatment-settling-stripping-adsorbent treatment-filtration, and

2. Chemical treatment-settling-stripping-solvent extraction.

These two trains can be termed adsorbent treatment and solvent treatment, respectively. Of course, distinctive elements of each may be included in the other to enhance results in a practical situation; this is a requirement for nothing more or less than process plant flexibility.

In terms of the processing estimates which are presented below, the two main process subsections can be considered to provide 1) standard, 2) adjusted, or 3) special processing. Standard processing refers basically to adsorbent treatment. Adjusted processing refers to adsorbent treatment with either treatment conditions or reagents adjusted beyond what is necessary for the common waste crankcase oils; adsorbent treatment preceeded by a rough solvent extraction could also be included in this processing category. Special processing refers to the basic solvent extraction treatment train. Other variations (based on variation of individual unit operations) are possible but the above suffices for preliminary design purposes.

Table 3. APPLICATION OF PLANT UNIT PROCESSES TO REMOVAL OF CONTAMINANTS FROM WASTE OILS

Contaminants	Removal Method
Water	Settling and Flash Distillation
Sediment (Coarse S.S.)	Settling and Filtration
Low-Boiling Hydrocarbons	Flash Distillation
High-Boiling Hydrocarbons	Solvent Extraction (or Flocculation/Settling)
Suspended Solids (fine)	Settling and Filtration
Color and Odor	Adsorbent Contacting
Acidic Compounds	Caustic Soda Neutralization, Adsorption
Organo-Metallics	Settling, Solvent Extraction, Adsorption
Pour Point Depressants	Solvent Extraction (may be left in for fuels)
V. I. Improvers	Solvent Extraction (may be left in for fuels)
Oxidation Products	Caustic Treatment, Adsorption
Corrosion Products	Settling, Filtration
Wear Products	Settling, Filtration
Dispersants	Precipitation, Solvent Extraction (may be left in for fuels)
Asphaltic Bodies	Solvent Extraction, Adsorption
Chlorine, Sulfur, Phosphorus (from Additive Packages)	Solvent Extraction, Chemical Reactions, Settling, Adsorption
Zn, Pb, Ba, Ca, Mg	Settling, Reactive Additive, Filtration

PROCESS SELECTION -- ULTIMATE DISPOSAL

The following paragraphs present the basic rationale for a waste oil incineration subsection. This presentation is necessarily brief since, in the first place, approaches to this sort of problem are speculative given the present state of technology and, second, very little is known of the actual character of the wastes which will be involved and the laws and regulations relating to their disposal. Final designs will have to firm up the incineration subsection considerably (perhaps even introduce radical changes); hopefully, this will be based on more definitive technical studies related to ultimate disposal.

Ultimate disposal of process residues and non-recoverable waste oils is a problem which must also be addressed. This is an area which has traditionally presented most operational problems in the re-refining industry. Ultimate waste disposal must be as efficient and environmentally sound as operations attendant to the rest of the processing facility. Table 4 lists the various unit operations and the wastes generated by each. Given the unit operations which have been selected, it is clear that solid, liquid, and gaseous wastes will be generated by the processing facility. Table 5 lists possible approaches to ultimate waste disposal. Option One is the most comprehensive and would put the most control over the disposal system in the hands of the State. Although capital costs would be much higher than for the other five techniques, this approach would:

1. Minimize the environmental impact of ultimate disposal by controlling waste streams and eliminating oily residues;

2. Produce concentrated, relatively pure residual wastes which should be disposable with relative ease to the heavy metals industry, landfill, and chemical industry;

3. Place ultimate disposal practices primarily under the aegis of the processing facility;

4. Assuming proper design, would vastly increase the flexibility of the facility for comprehensive waste oil recovery/disposal; and

5. Would do away with any possible oil pollution problems due to process residues.

With these factors in mind as well as the availability of incineration and stack gas scrubbing equipment, total incineration was, therefore, selected for preliminary design purposes. Appendix C contains an ultimate disposal process rating matrix which serves to summarize the analysis outlined above.

Table 4. GENERAL UNIT PROCESS WASTE GENERATION

Unit Process	Waste Generated*
A) Settling	BS&W (Bottoms, Sludge & Water)
B) Centrifugation	BS&W
C) Flash Distillation	Petroleum light ends and small amounts of water
D) Chemical Treatment	Process sludge
E) Sulfuric Acid Treatment	Highly acidic, oily process sludge
F) Vacuum Fractionation	Contaminated fractions (usually bottoms or residuum)
G) Hydrofining	Water, hydrogen sulfide, ammonia, metallic sludge, and carbon
H) Solvent Extraction	Process sludge
I) Adsorbent Treatment	Small amounts of vapor due to catalytic action; contaminated adsorbent
J) Filtration	Waste, contaminated clay, carbon or other solids

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* Based on the widest possible ranges of feedstock waste oils and, therefore, wastes generated

Table 5. ULTIMATE DISPOSAL PROCESS ALTERNATIVES

No.	Approach	Advantages	Disadvantages
1	Incinerate waste hydrocarbons, collect heavy metals for recovery and reuse and recover SO_2 and HCl as $CaSO_4$ and $CaCl_2$, respectively.	Storage and transport requirements are minimized. Plant not dependent on external shutdowns. Isolated solid residues are more easily handleable.	Higher capital cost than #3, #5, and #6. Facility would have to meet new EPA standards for emission.
2	Store waste materials for eventual disposal when better technology has been developed.	Capital cost lower initially than #1, but increasing with time. No discharges to air or water. Takes advantage of developing technology.	Potential costs. Deferred plant could be much more costly due to inflation. Seismic or meteorological incident could cause spill.
3	Purchase services of others to dispose of basic process wastes.	Capital cost is transferred to others.	Higher transportation, storage, and operating costs than #1, #2, #4, and #6. Liability for improper disposal will transfer to the MES. Loss of thermal value.
4	Incinerate wastes and dispose of all solids to land.	Storage facilities and transportation less than #3. Plant not dependent on external shutdown.	Toxic materials may contaminate soil and groundwater supplies. Also see #1. Transportation and landfill costs for disposal.
5	Dispose of all waste to land (private operator).	Lower capital cost than #1, #2, and #4. No airborne contaminant.	Toxic materials may contaminate groundwater and soil. Transportation and landfill costs. Plant very dependent on external shutdowns.
6	Dispose of all wastes to land (MES-owned & operated).	No airborne contaminants. Capital cost lower than #1, #2, and #4.	See #5. Less dependence on external shutdowns.

Previous paragraphs outlined the selection of total incineration for the non-recoverable waste oils and process residues. Simple incineration applies to oils or residues which are not contaminated with heavy metals, fine particulates, sulfur or halides yet cannot reasonably be turned into a valuable product; such material can be burned directly with only simple dust collection from the stack gases. Some waste edible oils as well as materials like fuel oil tank slops would be amenable to such treatment. Contaminated oils and residues will have to be burned under closely controlled conditions. Heavy metal particulates, sulfur dioxide and halides (primarily chloride) will have to be scrubbed from the controlled incinerator's stack gases and recovered as a particulate sludge, calcium sulfate, and calcium chloride, respectively. These materials should, in turn, be relatively easily disposable to the heavy metals industry, landfill and chemical industry, respectively.

BASIC PROCESS FEED FLOWS

The previous two subsections outlined the selection of various unit processes and process trains for the MES waste oil facility. These included three basic re-refining process trains (standard, adjusted and special) plus two incineration processes (simple and controlled). A sixth, but relatively minor, process flow is termed "Other Disposal" and refers to the economically viable sale of special waste oils to other parties.

Table 6 gives feed rates to each of the major processing alternatives as a function of gross waste oil category. These estimates are for a full-scale plant (22,000,000-gallons-per-year feed) operating 24 hours per day for 330 stream-days per year (a stream factor of about 90 percent). This list of feed rates provides a base for calculations relating to equipment selection, sizing, and pricing.

The analysis of Section IV on plant feed, receiving facilities and primary waste oil storage requires estimated flows to various process operations. These flows form a part of the basis for the preliminary design of a process plant as presented in this section. The process flow streams, as derived here, may be summarized as in Table 7.

Adjacent to the percentage column in Table 7 are estimates of variations in the process flows; in essence, these estimates provide a conservative upper bound (tentative) for each basic process flow stream. The percent errors for standard processing reflect the judgment that 41 percent of the total flow is probably already an optimistic value. For preliminary purposes, flows 10 percent higher or 35 percent lower could be expected. On the other hand, adjusted and special processing are liable to prove of considerable added importance in an actual process (especially for waste crankcase and industrial oils); 50 percent higher flows would not seem too unlikely while much lower values (say less than 10 percent) would.

Table 6. ESTIMATED STREAM-DAY FEED FLOWS (1975)

Category	Stream-Day Flow (gal)
Waste Crankcase Oil:	
Standard Processing	16,200
Adjusted Processing	9,800
Special Processing	5,000
Simple Incineration	2,100
Controlled Incineration	3,200
TOTAL	36,300
Waste Industrial Oil:	
Standard Processing	10,700
Adjusted Processing	3,100
Special Processing	2,400
Simple Incineration	1,800
Controlled Incineration	2,400
Other Disposal	300
TOTAL	20,700
Waste Fuel Oil:	
Adjusted Processing	1,800
Special Processing	1,200
Simple Incineration	1,200
Controlled Incineration	1,800
TOTAL	6,000
Waste Edible & Miscellaneous Oils:	
Special Processing	800
Simple Incineration	900
Controlled Incineration	1,000
Other Disposal	300
TOTAL	3,000

Table 7. PROCESS FLOW STREAMS

Processing Category	Flow (GPD)	Percent of Total	Probable Variation (% Higher/ % Lower)
Waste Crankcase Oil to Standard Processing	16,200	24.6	10/35
Waste Industrial Oil to Standard Processing	10,800	16.3	10/35
Waste Crankcase and Industrial Oil to Adjusted Processing	14,700	22.3	50/10
Waste Crankcase and Industrial Oil to Special Processing	7,800	11.8	50/10
Other Waste Oil to Special Processing	1,500	2.3	100/100
Waste Crankcase and Industrial Oil to Simple Incineration	4,200	6.4	100/50
Other Waste Oil to Simple Incineration	1,800	2.7	50/50
Waste Crankcase and Industrial Oil to Controlled Incineration	6,200	9.5	70/50
Other Waste Oil to Controlled Incineration	2,200	3.2	100/50
Other Waste Oil to Other Disposal	600	0.9	500/100
TOTALS	66,000	100.0	45/35

On a speculative basis, 100 percent greater flow of other waste oils to special processing would not seem unreasonable; lower values would be very significant; and zero would appear possible. All the waste crankcase and industrial oil which could prove not amenable to standard, adjusted, or special processing would end up by being incinerated; likewise, all the other waste oil could require incineration in an on-going operation. An additional 3,600 GPD incineration capacity (75 percent) is implied by these considerations. Processing "failure" would usually imply irreversible contamination of oils due to one cause or another; some such failure could mitigate against simple incineration (e.g., stabilization of lead additives). For preliminary purposes, increased incineration requirements due to waste crankcase and industrial oils are assumed to split 50/50 between simple and controlled; all additional other waste oils are assumed to require controlled incineration. On the other hand, incineration of both waste crankcase and industrial oils as well as other waste oils could quite conceivably be 50 percent of the values indicated so far.

The considerations above evolve a basis for final process design given that waste oil quality data is forthcoming or is appropriately estimated.

SMALL OR FIRST-STAGE PROCESSING FACILITY

The full-scale processing facility which was developed conceptually during the course of the project involves simultaneous processing of waste oils under different treatment conditions. It also would require fairly large capital and operating expenditures. As a possible first step in development of a full-scale processing facility, therefore, equipment and cost estimates were made for a scaled-down facility based on:

1. Using selected elements from the full-scale plant;
2. Maintaining the same processing capabilities as the full-scale plant but at a reduced throughput;
3. Incineration of much of the waste oils (non-recoverable) which would have to be incinerated at a full-scale facility;
4. Reducing the necessary plant operating staff from 22 to 17 men; and
5. Operating 24 hours per day for about 330 stream-days per year.

The results which follow from postulating such a reduced facility are presented in detail in this design report. Briefly, throughput is reduced to about 22,000 GPD of waste oil feedstock by taking this approach. Obviously, the overall processing system is no longer comprehensive, and some selectivity can be manifest in accepting feedstock.

SECTION IV

RECEIVING AND FEEDSTOCK TANKAGE

Existing re-refining operations generally involve a large amount of fairly small tankage. In a strict sense such tankage requirements were not developed using secure design bases. Rather, experience usually dictated the volume and number of tanks necessary, and changes and additions to tank farms are made as a fairly routine part of re-refining operations. The literature on waste oil re-refining reflects this situation in that tankage and its associated problems have not been explicitly studied. The logistics of receiving, handling, and storing waste oils have just not been detailed sufficiently. Although important for re-refining in the classic sense, such considerations are crucial for a comprehensive waste oil processing and disposal program. When large quantities of waste oil of highly variable composition are to be delivered to a central disposal site, the fashion in and frequency with which these oils arrive is of great importance; the plant subsection relating to this particular problem can be termed receiving tankage. Also, since different waste oils will require different processing, storage before processing is also of considerable concern. The tanks necessary to hold partially processed oils (especially in the case of batch processing) must also be considered. Product tankage is, of course, also an important concern; however, since it is highly dependent on the nature of a plant's product mix as well as product demand, a separate report section is devoted to this problem.

Sampling for analysis must be considered for both the process plant and the tank farm, including receiving tankage. Sampling at receiving tanks (through sample ports, sample lines, or with thiefs) will be used in establishing the nature of the waste oil being delivered and, therefore, the applicable charges for receiving same. It will also aid in routing the oil to primary storage. Sampling of stored waste oil (probably with thiefs) will serve to assist in routing the oil to the process plant.

As will be seen in Section VII, plant tankage accounts for about 29 percent of total plant capital cost and, therefore, must be considered carefully. Unfortunately, much relevant data is not and will not be available until comprehensive facilities are in operation. Total quantities of waste oil can be estimated from surveys or product sales data, but factors such as collection and delivery frequencies, peak-to-average generation rates, seasonal variations, yearly changes in waste oil character, and demand for re-refined oil products are not nearly so easily predictable. Educated guesses must be used in the absence of actual data on such factors. The problems just outlined are not dissimilar to those encountered with other types of waste materials. In fact, this report considers analogies to sewage and solid waste generation for the purposes of preliminary estimation. Final design efforts will, no doubt, have to involve a similar approach since surveys cannot supply the necessary detailed data; only operation of a full-scale facility can. In fact, one of the major benefits of full-scale comprehensive waste oil processing operations will be the generation of data suitable not only for facility modification but also for application nationwide.

The following subsections contain a detailed preliminary design analysis of process plant requirements for receiving and feedstock tankage.

RECEIVING TANKS

Initial receiving facilities must be able to handle the estimated peak flow (daily) for the plant. Present estimates are that routine waste oil collection will provide about 48,000 GPD of the plant feed with a variability comparable to that for municipal wastes (sewage and garbage/refuse); peak-to-average (daily) waste oil generation is, therefore, set at 2:1. About 12,000 GPD of waste oil feed stream will be much more variable in terms of collection and comprised of lube tank slops, contaminated lubes, etc.; a first estimate of daily collection variability for these waste oils is 5:1. Other waste oils (vegetable and animal oils and fats, transformer oils, jet fuel, waste detergent stocks, etc.) have not yet been the subject of any sort of generation rate measurements. For preliminary purposes, a value of 6,000 GPD will be assumed; peak-to-average input values should be set at the high variability ratio of 5:1 mentioned above.

Seasonal and yearly variations in waste oil input must also be considered. Yearly variations have been accounted for in the base feed rate estimate by using 1975 projected values; other than the projected, fairly uniform, yearly increase in waste oil generation, year-to-year variability (in the absence of catastrophic events) can be assumed to be of negligible significance. In the absence of more definitive data, seasonal variations can be assumed to track with monthly variations in gasoline sales (this should be a very good assumption for auto lube oils but only a rough approximation for the others). API data indicate that maximum and minimum gasoline consumption are plus and minus about one-eighth of the average, respectively. Turnover of the receiving tanks three times per day (once in the morning and twice in the afternoon) seems reasonable and must, therefore, be accounted for in sizing receiving tankage.

Given the basis for the primary plant feed rate and the above discussion on generation and collection variability, the required initial (daily) receiving facilities must have the following approximate daily storage capacities (Q):

Q routine lubes = 36,000 GPD
Q variable lubes = 22,000 GPD
Q other waste oils = 11,000 GPD

Routine waste lube oil collection will most probably involve moderately sized tank trucks from about 2,000 to 6,000 gallons. Receiving tanks should be sized to accept a typical load from such trucks and must provide a capability for obtaining representative composite samples of freshly delivered oil; that is, vertical tank compartments with vertically-spaced sample ports should be used for initial storage. Two 7,000- plus seven 3,000-gallon tanks should be provided for this service to account for the volumetric requirement estimated above. Although more labor-intensive, use of a sample thief may replace or augment sampling through ports.

The more variable waste lube oils are liable to be collected in smaller quantities (for the purpose of process feed segregation, they should be). Therefore, a number of smaller tanks (of similar geometric configuration to those mentioned above) would be convenient for initial storage. For preliminary purposes, a 50/50 split between 3,000- and 7,000-gallon tanks will be assumed at the present time. Therefore, two 7,000-gallon and three 3,000-gallon tanks will provide the necessary 22,000-gallon capacity.

Waste oils other than lubes will also be generated and collected in small quantities. Small tanks (minimum tank truck size) of 3,000-gallon capacity are, therefore, both desirable and should be adequate. Four such tanks satisfy the 11,000-gallon requirement.

The table on the following page (Table 8) illustrates receiving tank usage on what amounts to a nominal day. Extended work hours and/or overlap of the various functions indicated in the table would serve to provide the 2 or 3 receiving tank turnovers necessary on peak days.

Figure 1 of the tank farm includes the receiving tankage which is represented as four compartmented horizontal tanks.

FEEDSTOCK TANKS

Primary feed storage requirements depend on four basic factors:

1. Settling times necessary for preliminary processing since primary tanks will be used for this operation;

2. Probable process plant outages;

3. Expected periods of decreased waste oil collection services; and

4. Excess waste oil generation due to seasonal variations in auto/industrial usage and servicing.

The latter factor, which is of most importance, will be considered first. Waste automotive oil generation is likely to track closely with gasoline

Table 8. RECEIVING TANK REQUIREMENTS

	- Tank Size -	
	7,000 gal.	3,000 gal.
Unload Time	45 min.	30 min.
Sample Time	1	1
Prelim. Analysis Time	(<45)*	+15
Administrative Time	5	5
Subtotal -- Trucker Delay	51	51
Complete Analysis	60	60
Treatability -- Quality Control	240	240
Transfer Time	30	30
Load Factor (10%)	48	48
Contingency (10%)	48	48
TOTAL TIME	477 min. (8 hours)	477 min.** (8 hours)

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* Preliminary analysis takes less than the unloading time and is, therefore, not limiting.

** Therefore, if each tank receives and is emptied of only one load per 8-hour day,

14/day x 3,000 gal. = 42,000 gal.
4/day x 7,000 gal. = 28,000 gal.

OR 70,000 gal. of waste oil is handled.

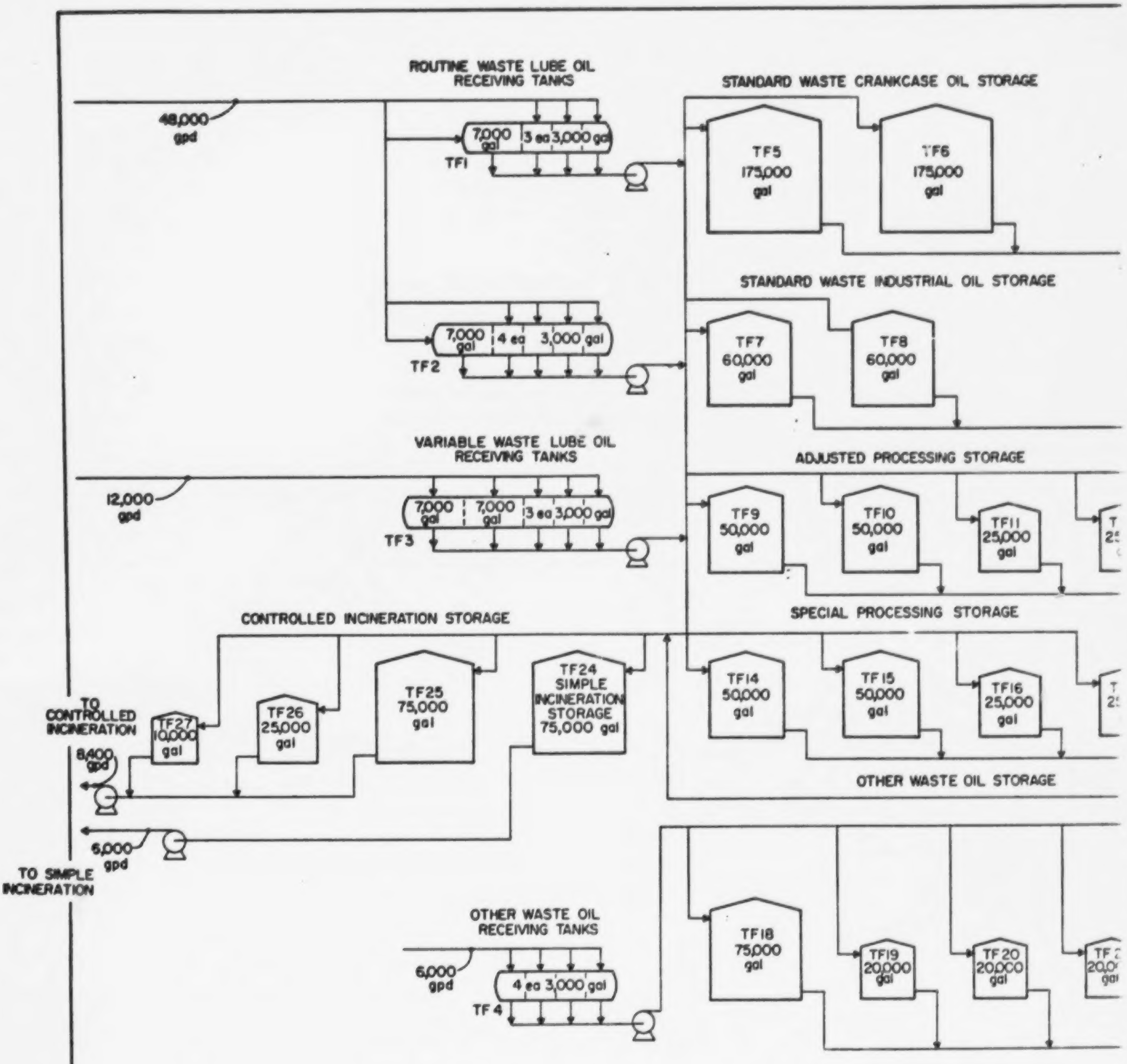
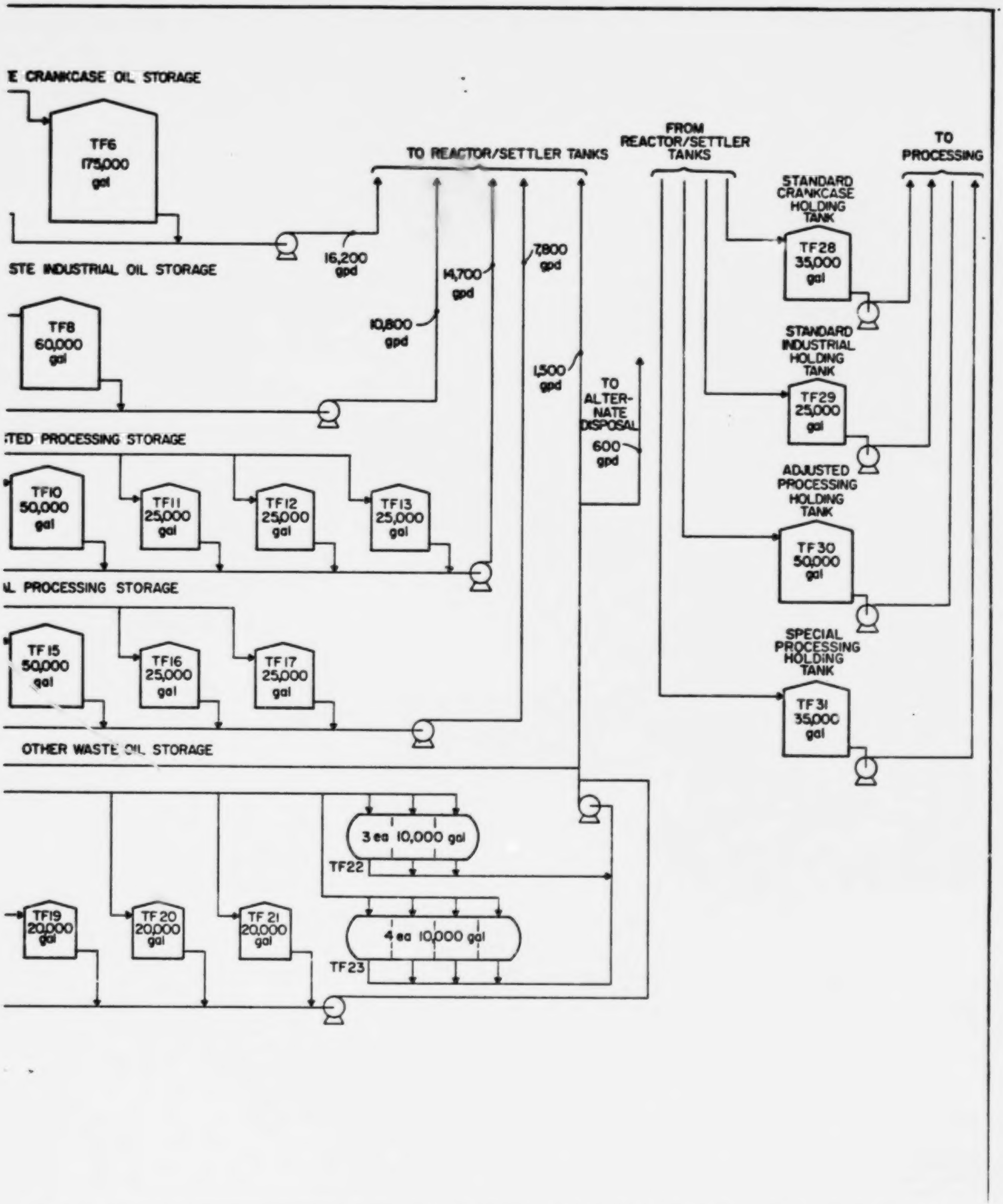

ROUTINE WASTE LUBE OIL RECEIVING TANKS
48,000 gpd
7,000 gal
3 ea 3,000 gal
TF1
STANDARD WASTE CRANKCASE OIL STORAGE
TF5 175,000 gal
TF6 175,000 gal
7,000 gal
4 ea 3,000 gal
TF2
STANDARD WASTE INDUSTRIAL OIL STORAGE
TF7 60,000 gal
TF8 60,000 gal
VARIABLE WASTE LUBE OIL RECEIVING TANKS
12,000 gpd
7,000 gal
7,000 gal
3 ea 3,000 gal
TF3
ADJUSTED PROCESSING STORAGE
TF9 50,000 gal
TF10 50,000 gal
TF11 25,000 gal
CONTROLLED INCINERATION STORAGE
SPECIAL PROCESSING STORAGE
TO CONTROLLED INCINERATION
TF27 10,000 gal
TF26 25,000 gal
TF25 75,000 gal
TF24 SIMPLE INCINERATION STORAGE 75,000 gal
TF14 50,000 gal
TF15 50,000 gal
TF16 25,000 gal
8,400 gpd
OTHER WASTE OIL STORAGE
6,000 gpd
TO SIMPLE INCINERATION
OTHER WASTE OIL RECEIVING TANKS
6,000 gpd
4 ea 3,000 gal
TF 4
TF18 75,000 gal
TF19 20,000 gal
TF 20 20,000 gal

Figure 1. PRELIMINARY MES WASTE OIL RECEIVING AND FEEDSTOCK TANKAGE


E CRANKCASE OIL STORAGE
TF6
175,000
gal
TO REACTOR/SETTLER TANKS
FROM
REACTOR/SETTLER
TANKS
TO
PROCESSING
STANDARD
CRANKCASE
HOLDING
TANK
TF28
35,000
gal
16,200
gpd
STE INDUSTRIAL OIL STORAGE
14,700
gpd
7,800
gpd
TF8
60,000
gal
10,800
gpd
1,500
gpd
TO
ALTER-
NATE
DISPOSAL
600
gpd
STANDARD
INDUSTRIAL
HOLDING
TANK
TF29
25,000
gal
TED PROCESSING STORAGE
TF10
50,000
gal
TF11
25,000
gal
TF12
25,000
gal
TF13
25,000
gal
ADJUSTED
PROCESSING
HOLDING
TANK
TF30
50,000
gal
L PROCESSING STORAGE
TF15
50,000
gal
TF16
25,000
gal
TF17
25,000
gal
SPECIAL
PROCESSING
HOLDING
TANK
TF31
35,000
gal
OTHER WASTE OIL STORAGE
3 ea 10,000 gal
TF22
TF19
20,000
gal
TF 20
20,000
gal
TF 21
20,000
gal
4 ea 10,000 gal
TF23

consumption. In the absence of more definitive data, seasonal gasoline consumption variations may be used as an estimate of relative variations in waste oil generation (automotive and industrial). The plot on consumption (Figure 2) presents some data for Maryland in 1969. Note that over an eight-month period (May through December), gasoline consumption averages 3.4 percent over the mean. Since the months of June, September, and November appear anomalous, a typical increased consumption of 5 percent is a more reliable design value. Additional storage required by a similar increase in waste oil consumption is:

$$Q_{\text{waste lube oils, xs}} = 500{,}000 \text{ gallons.}$$

Typically, process plants can expect a maximum (say, with 95 percent expectation) downtime of about 3 days. Obviously, catastrophes are not covered by such an outage value. The extra receiving capacity for this outage can also serve to buffer the effects of any oil collection activities on weekends. Outage may occur under peak (maximum collection rate) and storage-restrictive (e.g., mid-summer) conditions. If half the three-day outage is assumed to involve peak waste oil delivery and the other half average delivery, the equivalent required storage capacity is:

$$Q_{\text{waste lube oils, outage}} = 324{,}000 \text{ gallons.}$$

Whether or not the excess storage capacity is being used or the plant is experiencing an outage, time for primary settling of BS&W from the waste oil is required. Such tankage will be part of the process plant but must still be considered as part of the capacity available for storage. A conservative estimate (under nominal design conditions) for waste oil settling is 72 hours. This requires a process tank capacity of:

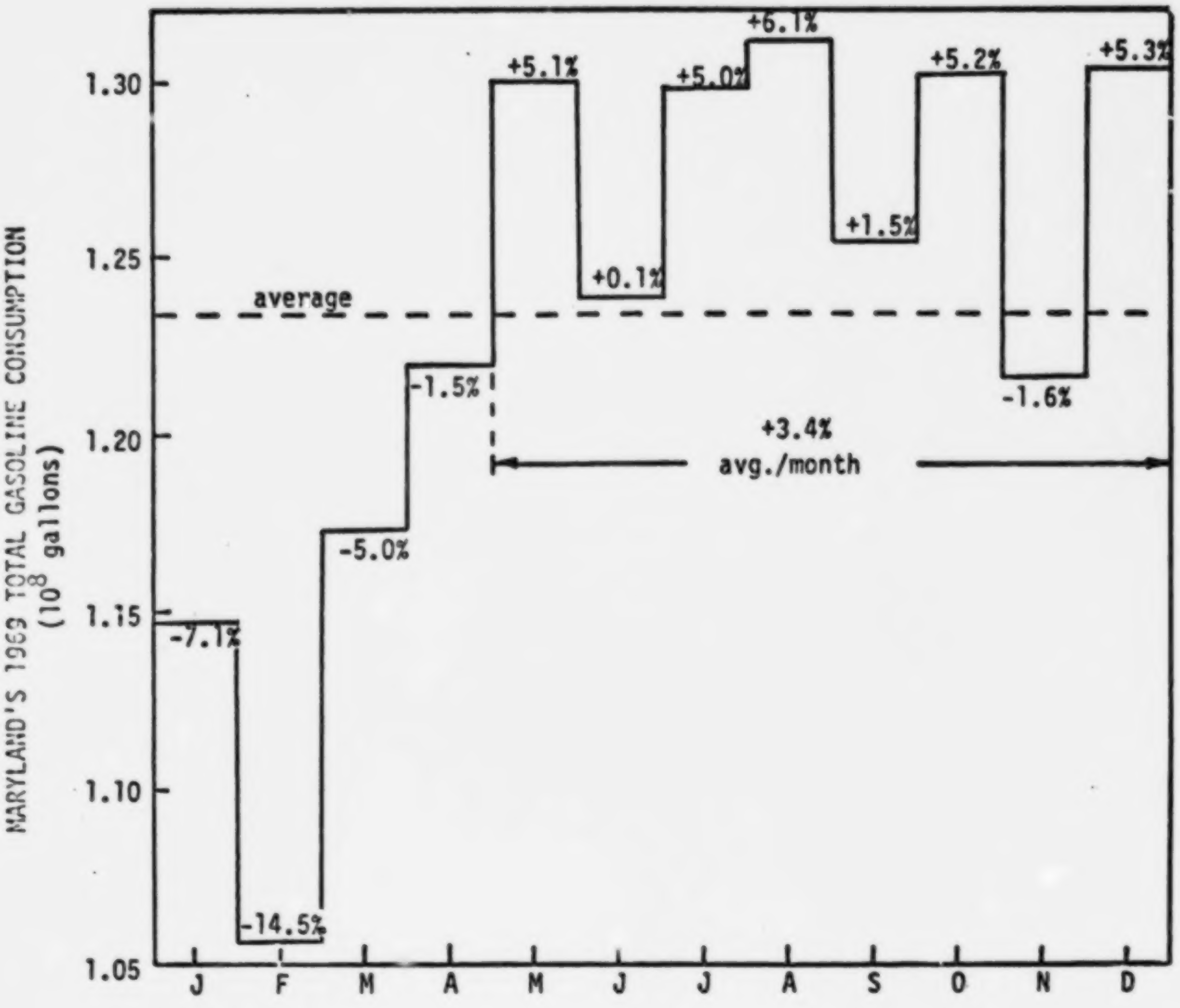
$$Q_{\text{waste lube oils, settling}} = 180{,}000 \text{ gallons.}$$

Decreased waste oil collection activity (e.g., due to holiday periods or strikes) would require additional stored waste oil to make up for decreased amounts of freshly delivered oils. However, holiday inactivity would most likely occur in November and December when excess waste oil was already in storage; additional storage capacity is, therefore, not required to account for this factor. Effects due to strikes of labor forces outside the plant (e.g., truck drivers) could eventually bring a halt to plant operations; this could occur quickly in the spring or after quite an extended period in the winter when considerable excess waste oil is already in storage waiting to serve as plant feed. Additional storage to account for decreased waste oil collection activity will not be included in the preliminary plant design.

The above considerations point to a total primary waste oil storage capacity of:

$$Q_{\text{waste lube oil, total primary storage}} = 1{,}000{,}000 \text{ gallons.}$$

Figure 2. MONTHLY GASOLINE CONSUMPTION IN MARYLAND



This waste lubricating oil storage is for both routinely deliverable (about 800,000 gallons) and variably deliverable (about 200,000 gallons). Initial estimates are that about 50 percent of the routinely deliverable oil will be amenable to standard processing; that is, 400,000 gallons each must be allocated for standard and non-standard processable but routinely deliverable waste lube oils. Of the variably deliverable waste oils, only about 25 percent will be processable by standard techniques; standard and non-standard storage, therefore, has to be about 50,000 and 150,000 gallons, respectively.

The required total storage of waste lube oil amenable to standard processing is 450,000 gallons which may be further subdivided into about 270,000 gallons for waste crankcase oils and 180,000 gallons for waste industrial oils. Therefore, two 30,000-gallon reactor/settler tanks plus a 35,000-gallon holding tank (See the subsections on process design which follow) and two 175,000-gallon main feed storage tanks should serve for waste crankcase oils. Similarly, the waste industrial oils will require two 20,000-gallon reactor/settlers, a 25,000-gallon process holding tank, and two 60,000-gallon feed storage tanks.

The remaining waste lube oil (55 percent of the incoming waste lube oil) is either amenable to adjustable processing (e.g., additional settling time with different or higher concentrations of flocculants and demulsifiers) or special processing (e.g., solvent extraction) or is overly contaminated but amenable to simple (e.g., for waste oil mixed with organic acids in high concentrations) or controlled incineration (e.g., for oil mixed with chlorinated solvents). Previously, the total gallons of storage capacity required for these oils was estimated to be about 550,000 gallons. For the purpose of preliminary estimates and for routinely deliverable waste lube oils, adjustable processable, specially processable, simply incineratable and specially incineratable oils can be assumed to require 50, 25, 10, and 15 percent of the storage volume (400,000 gallons), respectively. Analogous estimates for the variably deliverable waste lube oil are 30, 20, 20, and 30 percent, respectively. Based on these figures, gallonage for the four basic categories are 245, 130, 70, and 105 thousand gallons, respectively. A single 70,000-gallon tank should serve for the simply incineratable oils since these will, by definition, have to be relatively innocuous. More flexibility will be required in handling the materials which require controlled incineration. Three tanks of 10,000-, 25,000-, and 75,000-gallon capacities should suffice to permit selective holding of materials for carefully controlled incineration.

For waste lube oil amenable to adjusted processing, a nominal settling time of 6 days (twice the value of routine processing) is reasonable for preliminary purposes. Since this oil, on the average, comprises about 24 percent (or 14,700 GPD) of the feed stream, but has already been considered for 3 days' settling, only 45,000 gallons extra storage capacity is required or 290,000 gallons total. Adjusted processing will be required with a considerable degree of specificity; therefore, two 45,000-gallon reactor/settlers, plus a 50,000-gallon holding tank and feed storage tanks of 25 (3) and 50 (2) thousand-gallons are desirable.

Waste oils recoverable by special processing need not necessarily require additional settling time; however, they most probably will have to be held for considerable periods of time until an appropriate process or disposal method can be selected. An additional two weeks' residence time in the storage tanks would not be unusual for such an operation. Since an average of 7,800 GPD of this type waste lube oil is involved, additional storage of 110,000 gallons is implied for a total of 240,000 gallons. Special processing must also consider other waste oils.

Other waste oils (See the following paragraphs) will also be partially amenable to special processing accounting for a total flow of 9,300 GPD. Two 30,000-gallon reactor/settlers and a 35,000-gallon holding tank will permit preliminary treatment of this total special processing stream. The remaining 150,000 gallons of storage should be allocated to two 25,000- and two 50,000-gallon tanks.

Other waste oils will be subject primarily to incineration and special disposal. In-plant recovery will probably be quite limited (something like waste transformer oils may eventually prove processable). As with the waste lube oils, seasonal variations and probably plant (e.g., incinerator) outages must be considered. Decreased waste oil collection services and settling have essentially no effect on storage since these materials will not be cycled through the primary process loop. Holding for special treatment or disposal must be considered; four weeks' holding is reasonable for such a function. Total required primary storage capacity for other waste oils, therefore, is:

$$Q_{\text{other waste oils}} = 205{,}000 \text{ gallons.}$$

Other waste oils, as referred to above, can be expected to include materials such as: transmission fluid, jet fuel, tank slops and sludges, fuel oils, coolants, animal and vegetable oils, ink oils, recovered spilled oil, and detergent stocks. Not only is total other waste oil generation for the State of Maryland unknown, but the processability of other waste oils is not at all well defined. For the purposes of preliminary design, assumptions must, therefore, be made as to other waste oil treatability. Since much of the material will be of the nature of "slops" or highly contaminated organics, 30 and 35 percent to simple and controlled incineration, respectively, have been assumed.

A small amount of the material will require or be amenable to special (other) disposal techniques which are not available at the demonstration plant; this amount will be assumed to be 10 percent. The remaining 25 percent is assumed treatable by special processing. Therefore, for the other waste oil stream, simple incineration, controlled incineration, special processing and other disposal involve 1,800, 2,100, 1,500, and 600 gallons per day, respectively. Likewise, of the 205,000 gallons of primary storage, 65, 70, 50, and 20 thousand gallons should be allocated to each of the four categories, respectively. For preliminary purposes, relatively small primary feed storage tanks of 10 (7), 20 (3), and 75 (1) thousand gallons should serve for these other waste oils.

For conceptual purposes, the various tank farm elements of the previous paragraphs have been considered as independent entities. In reality, however, they can (problems of cross-contamination kept to a minimum) be used interchangeably. The total tank capacity required, however, remains the same since, as has been indicated, peak flows and storage overloads for the various categories can occur simultaneously; this, in fact, will probably be the case for any full-scale operation.

LAND REQUIRED

As might be expected, the multiplicity of tanks necessary for waste oil receiving and feed storage plus reactor/settlers (covered in the next section) and product tanks requires that a considerable portion of the plants' land area be devoted to tankage. Physical size, diking, and tank separation all contribute to the area required for tanks. Such factors are set in final design by using criteria such as the API's standards for petroleum storage tanks.

Table 9, on the following page, summarizes the preliminary site area requirements for the primary waste oil storage tanks and the reactor/settler and holding tanks which are discussed in more detail in the following major section on the process plant.

TANK FARM FLOWSHEET

The information found on Figure 1 (page 28) summarizes the quantitative results of the previous sections in the form of a preliminary design flowsheet for the waste oil tank farm. This flowsheet includes waste oil receiving and primary feedstock storage tanks plus four process holding tanks which are detailed in the following section on the process plant. Reactor/settler tanks are included in the preliminary design flowsheet for the process plant itself. Product tankage is considered in a following section but is not illustrated here due to its relatively great simplicity. The following paragraphs discuss this flowsheet in more detail with careful attention to probable variations in flow values.

TANK COST ESTIMATES

Based on the information covered under tank requirements, cost estimates can be made for each of the tanks used for receiving, feedstock storage

Table 9. FEED TANK AREA REQUIREMENTS

Volume (gallons)	Number of Tanks	Area per Tank (Ft^2)	Total Area (Ft^2)
Primary Waste Oil Storage Tanks			
10,000	8	600	4,800
20,000	3	1,000	3,000
25,000	6	1,100	6,600
50,000	4	1,700	6,800
60,000	2	1,900	3,800
75,000	3	2,200	6,600
175,000	2	3,900	7,800
		Total	39,400
Reactor/Settler and Holding Tanks			
30,000	4	1,200	4,800
35,000	2	1,300	2,600
20,000	2	1,000	2,000
25,000	1	1,100	1,100
50,000	1	1,700	1,700
45,000	2	1,600	3,200
		Total	15,400

and process holding. Table 10, below, calls out the cost for each of the tanks represented on the tank farm flowsheet of the previous subsection. These are installed costs (direct cost less foundations) which will be used in Section VII in making total capital cost estimates.

Table 10. RECEIVING, FEEDSTOCK STORAGE & PROCESS HOLDING TANK COSTS

Tank No.	Type	Volume (gal.)	Installed Cost
TF 1	Receiving	16,000	$ 10,800
TF 2		19,000	13,200
TF 3		23,000	14,800
TF 4		12,000	9,300
TF 5	Feedstock Storage	175,000	26,000
TF 6		175,000	26,000
TF 7		60,000	16,500
TF 8		60,000	16,500
TF 9		50,000	14,600
TF 10		50,000	14,600
TF 11		25,000	9,900
TF 12		25,000	9,900
TF 13		25,000	9,900
TF 14		50,000	14,600
TF 15		50,000	14,600
TF 16		25,000	9,900
TF 17		25,000	9,900
TF 18		75,000	19,200
TF 19		20,000	8,700
TF 20		20,000	8,700
TF 21		20,000	8,700
TF 22		30,000	14,600
TF 23		40,000	18,300
TF 24		75,000	19,200
TF 25		75,000	19,200
TF 26		25,000	9,900
TF 27		10,000	5,900
TF 28	Process Holding	35,000	12,100
TF 29		25,000	9,900
TF 30		50,000	14,600
TF 31		35,000	12,100
	TOTALS	1,400,000	$422,000

SECTION V

PROCESS PLANT

Using the basic processing approach outlined in Section III, a preliminary design for a waste oil recovery process plant was undertaken. Basic equipment requirements relate to reaction/settling, adsorbent treatment, solvent extraction, and incineration as already outlined. Land required for the processing section of the proposed facility is also considered in the following paragraphs. Finally, item-by-item preliminary cost estimates are given for all major pieces of hardware; these are, in turn, used in Section VII in developing total capital cost estimates.

The remainder of this report section summarizes in detail the unit operations required to provide the process facility which was specified in Section III in a general sense.

BASIC PROCESS FLOWSHEET

Based on the process selection (Section II) and equipment requirements as outlined, a flowsheet was developed describing the proposed process plant. This preliminary MES Waste Oil Recovery System flowsheet is presented on page 38. Each of the equipment items refers to one of those which must be called out in detail. The tank farm and process holding tanks are not represented on this drawing. Feed from the tank farm to the process tanks (reactor/settlers, T1 to T8) and incinerators (IN1 and IN2) is symbolized by the arrows entering the flowsheet from the left and right sides of Figure 3, respectively. Feed to and discharge from the process holding tanks are represented by the two connections and valves after each pair of reactor/settlers.

The flexibility and comprehensive nature of this particular process scheme are readily apparent upon detailed examination of the flowsheet. Adsorbent treatment and solvent extraction subsections are closely interconnected. Feedstocks can, therefore, be treated in highly specialized fashions. Liquid, solid, and vaporous wastes are all sent to the incineration subsection for ultimate disposal. Oxidation results in the formation of harmless carbon dioxide and water vapor, as well as particulates (with high metallic content), sulfur dioxide and hydrogen halides. The latter materials are scrubbed from the incinerator stack gases and recovered as relatively innocuous calcium sulfate and calcium halides. The metallic particulates are recovered by scrubbing and filtering as a compact, solid mass for sale to others.

Figures 4 and 5 represent a generalized version of this basic flowsheet and were presented as such in the main report for the project.

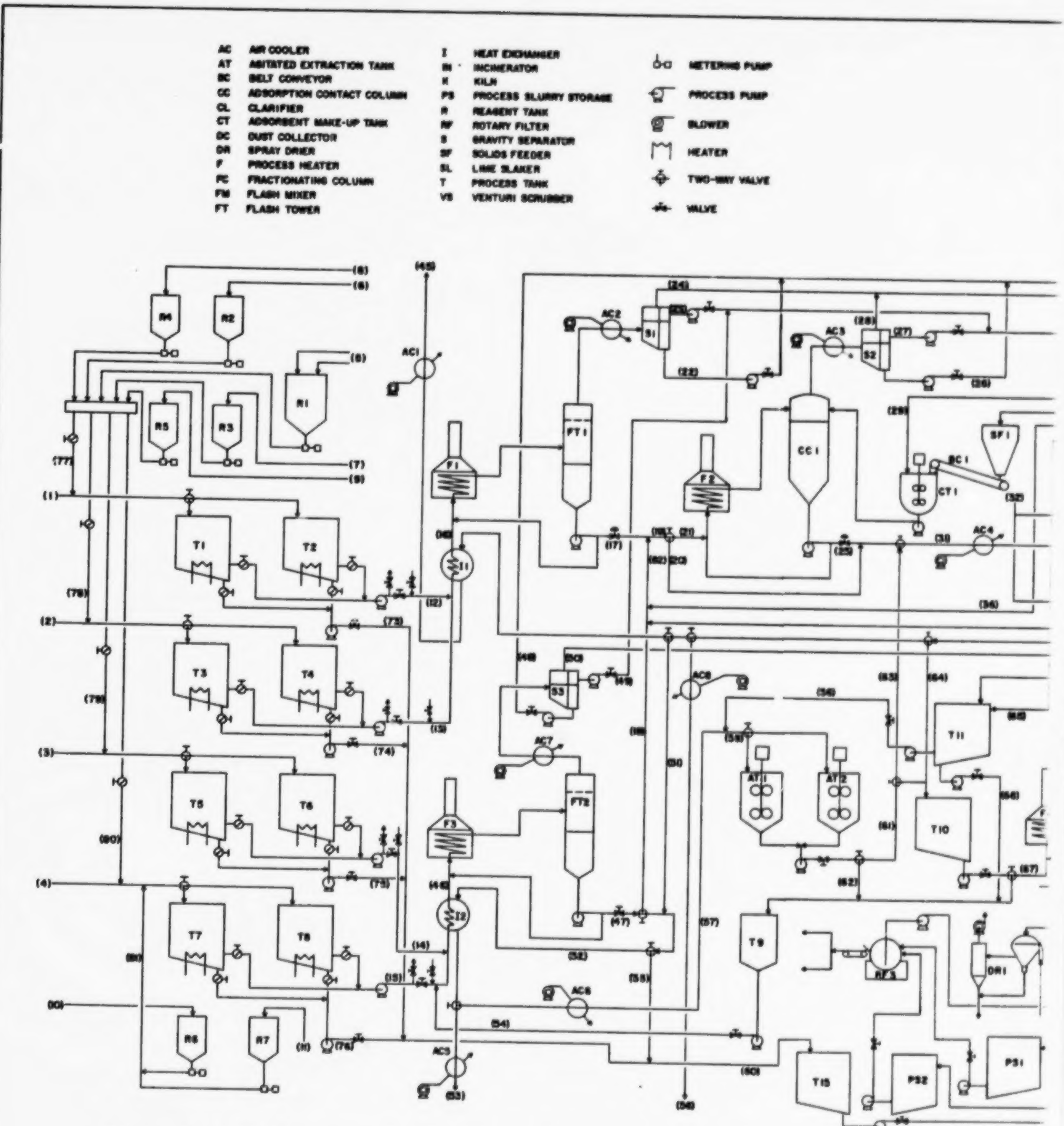

AC AIR COOLER
AT AGITATED EXTRACTION TANK
BC BELT CONVEYOR
CC ADSORPTION CONTACT COLUMN
CL CLARIFIER
CT ADSORBENT MAKE-UP TANK
DC DUST COLLECTOR
DR SPRAY DRIER
F PROCESS HEATER
FC FRACTIONATING COLUMN
FM FLASH MIXER
FT FLASH TOWER
I HEAT EXCHANGER
IN INCINERATOR
K KILN
PS PROCESS SLURRY STORAGE
R REAGENT TANK
RF ROTARY FILTER
S GRAVITY SEPARATOR
SF SOLIDS FEEDER
SL LIME SLAKER
T PROCESS TANK
VS VENTURI SCRUBBER
METERING PUMP
PROCESS PUMP
BLOWER
HEATER
TWO-WAY VALVE
VALVE
R4
R2
R1
R5
R3
AC1
F1
FT1
I1
AC2
S1
AC3
S2
F2
CC1
CT1
BC1
SF1
AC4
T1
T2
T3
T4
T5
T6
T7
T8
S3
AC6
AC7
F3
FT2
I2
AT1
AT2
T11
T10
T9
RF1
DR1
AC5
AC8
R6
R7
T15
PS2
PS1

Figure 3. PRELIMINARY MES WASTE OIL RECOVERY SYSTEM --

- FLOW SHEET -

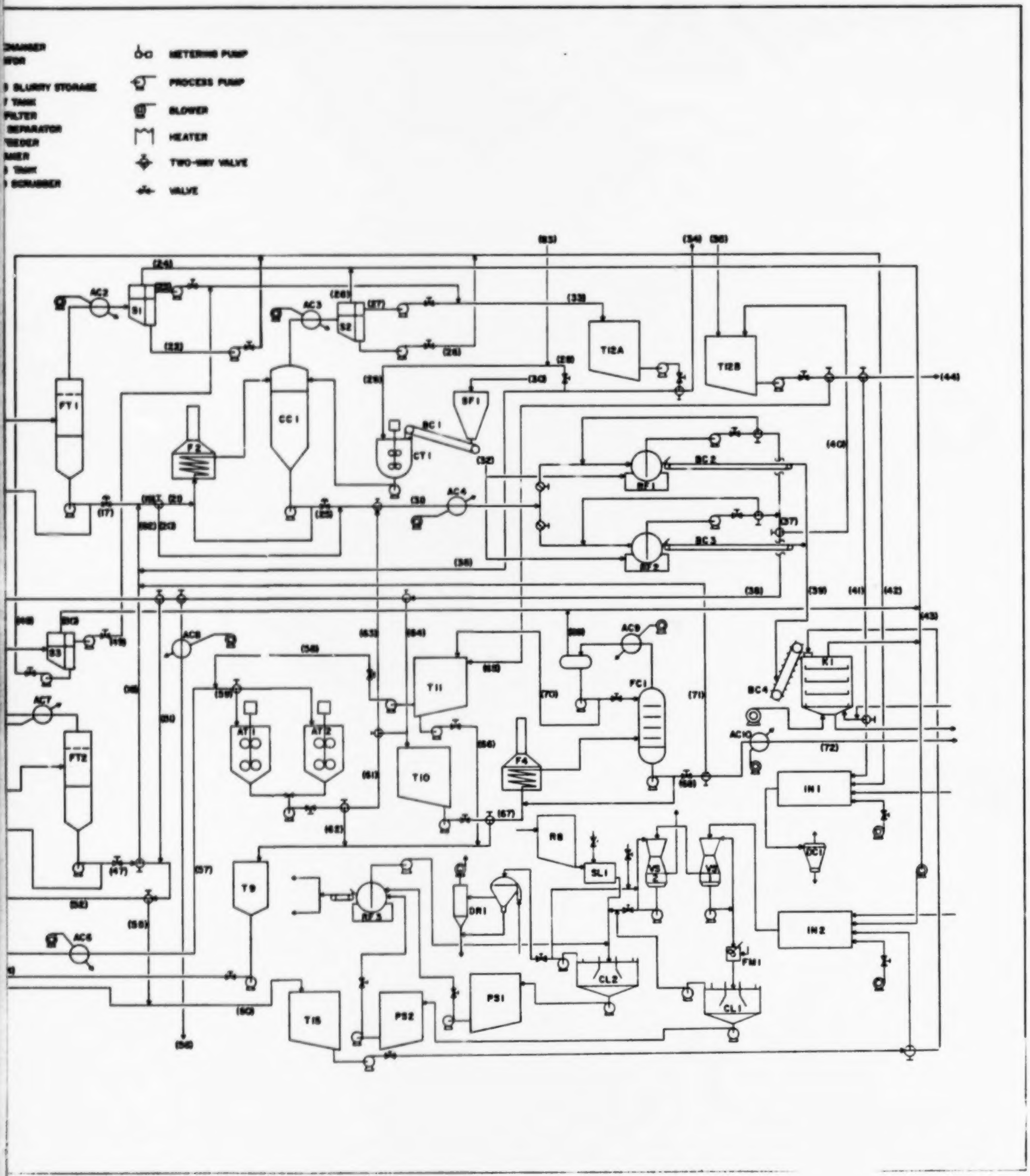

SLURRY STORAGE
TANK
FILTER
SEPARATOR
FEEDER
SCRUBBER
METERING PUMP
PROCESS PUMP
BLOWER
HEATER
TWO-WAY VALVE
VALVE
AC2
S1
AC3
S2
FT1
CC1
F2
CT1
BC1
SF1
T12A
T12B
AC4
BC2
RF1
BC3
RF2
S3
AC8
AC7
FT2
AT1
AT2
T11
T10
F4
AC9
FC1
K1
BC4
AC10
IN1
IN2
DC1
RS
SL1
V2
V3
FM1
CL1
CL2
T9
RF3
DR1
AC6
T15
PS2
PS1
(17)
(20)
(21)
(22)
(24)
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Figure 4. ADSORBENT AND SOLVENT TREATMENT SUBSECTION SCHEMATIC

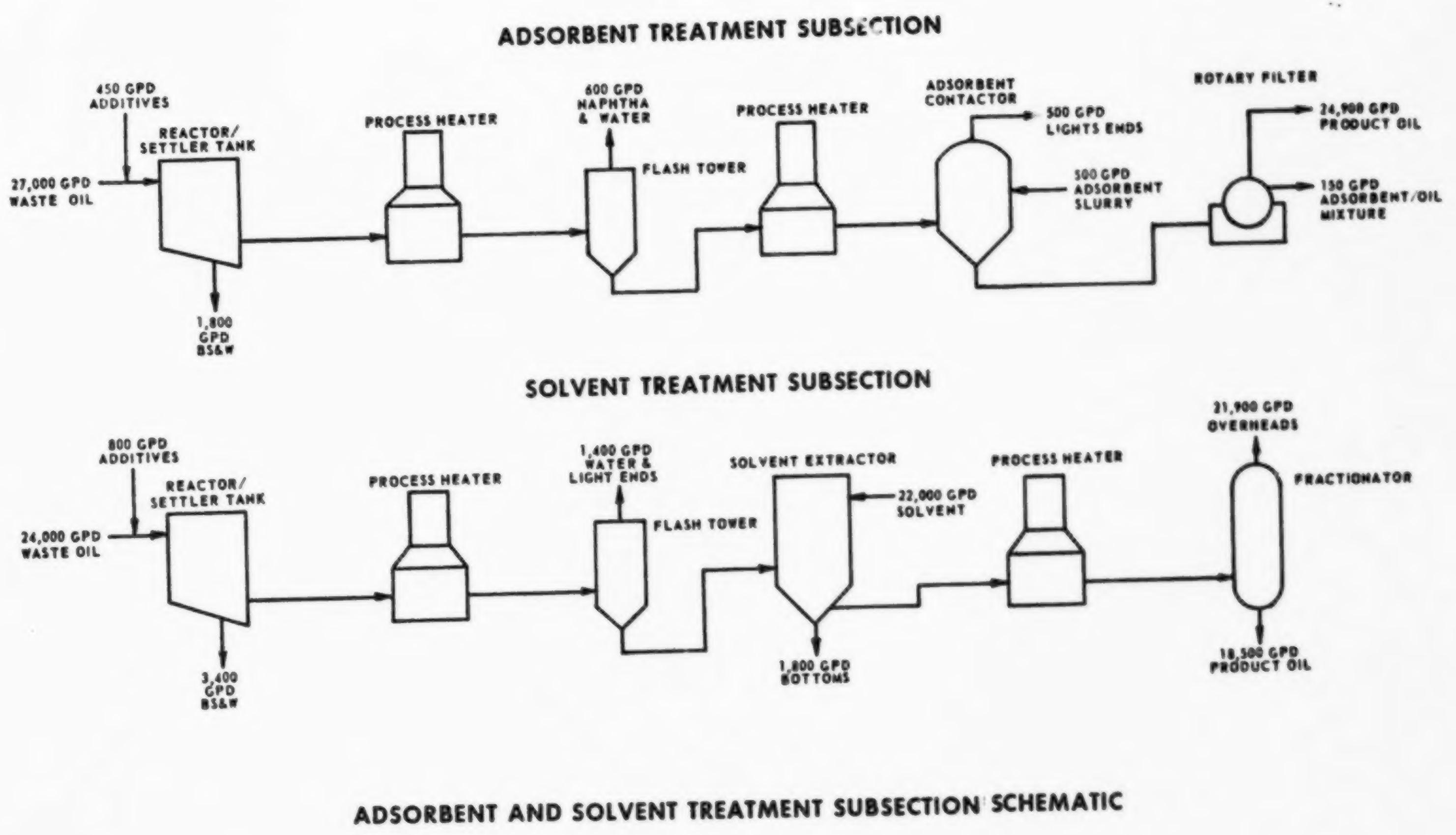
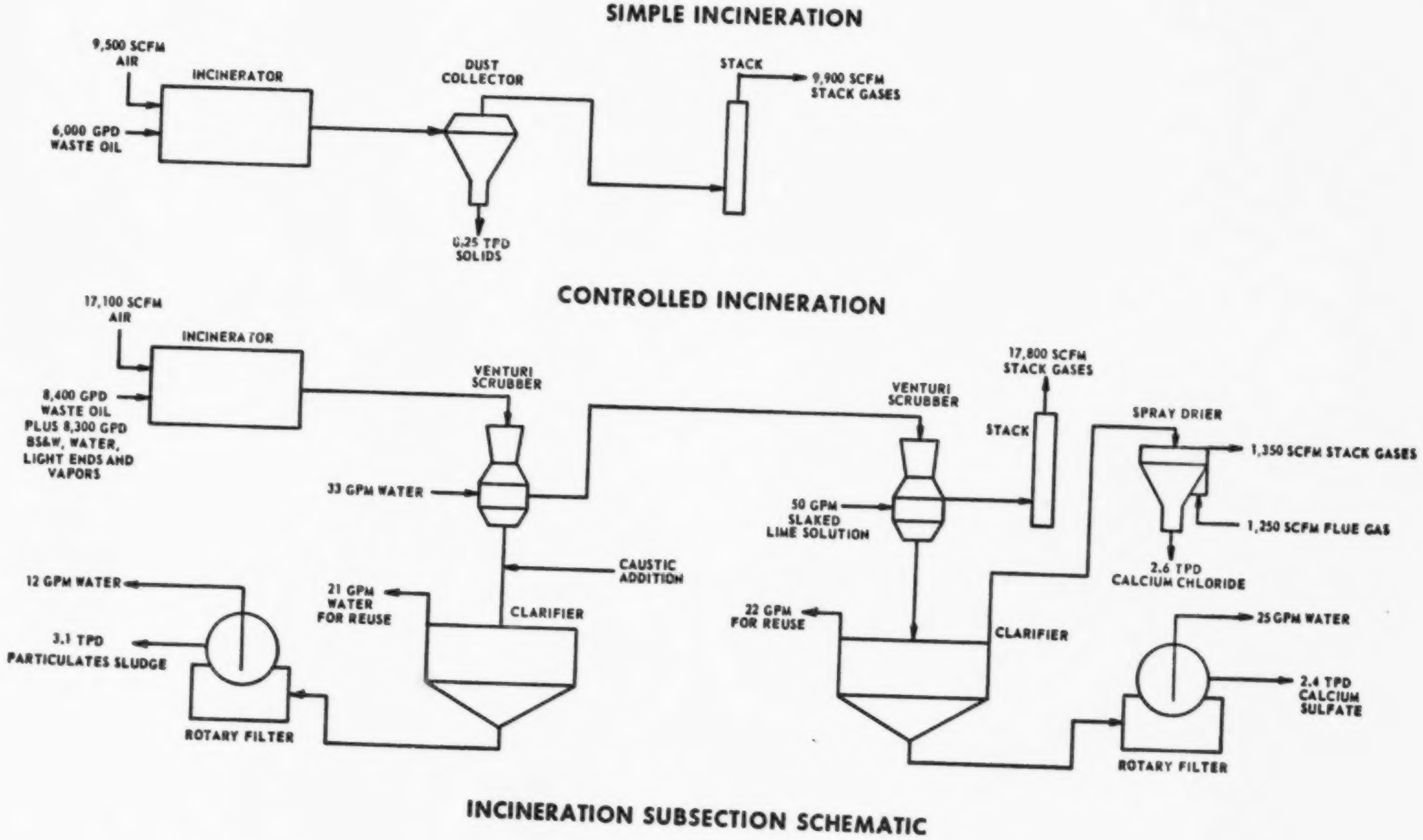

ADSORBENT TREATMENT SUBSECTION
450 GPD ADDITIVES
27,000 GPD WASTE OIL
REACTOR/ SETTLER TANK
1,800 GPD BS&W
PROCESS HEATER
600 GPD NAPHTHA & WATER
FLASH TOWER
PROCESS HEATER
ADSORBENT CONTACTOR
500 GPD LIGHTS ENDS
500 GPD ADSORBENT SLURRY
ROTARY FILTER
24,900 GPD PRODUCT OIL
150 GPD ADSORBENT/OIL MIXTURE
SOLVENT TREATMENT SUBSECTION
800 GPD ADDITIVES
24,000 GPD WASTE OIL
REACTOR/ SETTLER TANK
3,400 GPD BS&W
PROCESS HEATER
1,400 GPD WATER & LIGHT ENDS
FLASH TOWER
SOLVENT EXTRACTOR
22,000 GPD SOLVENT
1,800 GPD BOTTOMS
PROCESS HEATER
21,900 GPD OVERHEADS
FRACTIONATOR
18,500 GPD PRODUCT OIL
ADSORBENT AND SOLVENT TREATMENT SUBSECTION SCHEMATIC

Figure 5. INCINERATION SUBSECTION SCHEMATIC


SIMPLE INCINERATION
9,500 SCFM AIR
6,000 GPD WASTE OIL
INCINERATOR
DUST COLLECTOR
0.25 TPD SOLIDS
STACK
9,900 SCFM STACK GASES
CONTROLLED INCINERATION
17,100 SCFM AIR
8,400 GPD WASTE OIL PLUS 8,300 GPD BS&W, WATER, LIGHT ENDS AND VAPORS
INCINERATOR
VENTURI SCRUBBER
33 GPM WATER
CAUSTIC ADDITION
21 GPM WATER FOR REUSE
CLARIFIER
12 GPM WATER
3.1 TPD PARTICULATES SLUDGE
ROTARY FILTER
VENTURI SCRUBBER
50 GPM SLAKED LIME SOLUTION
STACK
17,800 SCFM STACK GASES
22 GPM FOR REUSE
CLARIFIER
SPRAY DRIER
1,350 SCFM STACK GASES
1,250 SCFM FLUE GAS
2.6 TPD CALCIUM CHLORIDE
25 GPM WATER
2.4 TPD CALCIUM SULFATE
ROTARY FILTER
INCINERATION SUBSECTION SCHEMATIC

EQUIPMENT REQUIREMENTS

The previous sections analyzed the available options for waste oil re-refining and ultimate waste disposal. Based on this analysis, the following basic processes must (to allow for removal of relevant contaminants) be included in the waste oil recovery and disposal facility whose preliminary design is a portion of this report:

1. Chemical Treatment/Settling
2. Stripping
3. Adsorbent Treatment
4. Filtration
5. Solvent Extraction
6. Incineration
7. Particulates Recovery
8. SO_2 and HCl Recovery

The unit operations included in the preliminary design flowsheet conform generally to these basic processes. The following pages discuss the unit operations in more detail with emphasis on preliminary equipment sizing and specifications.

Reactor/Settler Tanks

Heating, mixing and quiescent conditions for settling are required of these tanks. Careful control over batchwise processing weighs against tanks of very large size; therefore, for the purpose of preliminary estimates, tank volumes should be limited to 50,000 gallons or less. Fortunately, tanks larger than this appear not to be required. Since present practice and the high variability of waste oils are not conducive to continuous reaction/settling at the front end of the plant, batchwise processing is required. Maximum utilization of these tanks (which are relatively expensive due to the extensive control requirements) requires use of process holding tanks to contain oil for feeding to the rest of the process plant; in this fashion, the reactor/settler tanks themselves can essentially be in operation 24 hours per day.

Each reactor/settler tank must be insulated to permit efficient temperature control at about 200°F; sloped bottoms must also be provided to permit efficient removal of settled BS&W and relatively complete drainage of processed oil on a batch-to-batch basis. Each reactor/settler tank must also be provided with a heating capability which is a costly proposition; 50 to 60 cents per gallon of capacity is not unusual for heating capital investment in reactors. Of course, agitators must also be provided for these tanks; low energy, paddle-type, impellers should be used.

Reactor/settler tank sizes are fixed by the required processing time and nominal throughput. About 20 percent excess tank volume should be provided to allow for freeboard and volumetric expansion upon heating. Additionally, special considerations should be given to complete, and safe, venting of these tanks to the incinerator subsection of the plant as well as special fittings, valves and ports to provide an extensive sampling capability. Since the chemical treatment selected will involve, primarily, addition of surfactants and caustic, carbon steel construction should suffice.

There are four basic waste oil streams which require reaction/settling. Waste crankcase oils amenable to standard processing must be treated at about 16,200 gallons per day; typically, such processing in the existing waste oil re-refining industry involves about 3 days for heating, mixing, and reaction, followed by settling. Therefore, approximately 50,000 gallons of waste oil must be processed in this category every three days; two 30,000-gallon agitated tanks (T1 and T2) should serve for this operation if freeboard and expansion allowances are included. In addition, a holding tank of slightly larger volume (T28) must be provided to permit maximum utilization of the two basic reactor/settler tanks.

Waste industrial oils amenable to standard processing are to be treated at about 10,800 gallons per day with, again, a three-day treatment time. Therefore, the requirement here is for two 20,000-gallon reactor/settlers (T3 and T4) and a like-sized process holding tank (T29).

Waste oils will be subjected to adjusted processing at 14,700 gallons per day with about a six-day treatment time. Therefore, two 45,000-gallon reactor/settler tanks (T5 and T6) and a similar-sized holding tank should suffice (T30).

Special processing involves only 9,300 gallons per day with six-day treatment so that two 30,000-gallon reactor/settler tanks (T7 and T8) and a single 35,000-gallon holding tank (T31) are required.

Reagent tanks must be provided for addition of chemicals (e.g., caustic, flocculants, demulsifiers and oxidizers) to the reactor/settler tanks. An average 1:100 ratio of added caustic solution to waste oil at the reactor/settler tanks implies about 500 gallons a day of caustic solution addition; a week's operation without tank refilling, therefore, requires a reagent tank of about 2,500 gallons (R1). Oxidant addition may also be substantial; if the waste crankcase oils to standard and adjusted processing require averages of about 1/2 and 1-1/4 percent oxidant addition, a 1,000-gallon tank (R5) should serve for about one week's operation. Other reagents (e.g., flocculants) will be added at much lower levels; if average addition were 100 ppm with 10 percent concentration of reagent in a carrier oil, a 275-gallon tank would be more than sufficient for a week's operation. Five such tanks (R2, R3, R4, R6, and R7) are assumed for the purposes of preliminary design. Given potentially corrosive storage conditions, these tanks would best be constructed of 316 stainless steel.

Adsorbent Treatment Subsection

The following paragraphs serve to describe the basic equipment elements which comprise the adsorbent treatment subsection of the waste oil recovery and disposal plant. Present estimates are that 25,500 gallons per day of waste oil will be the primary adsorbent treatment feed (No.16). Note, however, that various unit operations in this plant subsection are used to treat other materials and are, therefore, sized accordingly. The primary feed to adsorbent treatment is composed of 15,000 gallons per day from waste crankcase oils and 10,500 gallons per day from waste industrial oils; about 1,860 gallons per day of BS&W, associated with this stock, is sent to incineration after separation in the preceding reactor/settlers.

Heat Exchanger (I1) --

The stream indicated above first exchanges heat with the product stream from the adsorbent treatment subsection. This serves to both preheat the feed stream before entering the following process heater and cool the product stream before storage. For the purpose of preliminary design, a zero-degree approach was assumed for this heat exchanger; that is, the two exit streams from the exchanger were assigned the same temperature. Both streams are of about the same mass (See the mass/energy balance summaries) while the inlet feed oil is at about 200°F (nominal reaction settling temperature) and the inlet product oil is at about 400°F; therefore, the exit temperatures are about 300°F. The overall oil-to-oil heat transfer coefficient for exchangers was estimated at 15 Btu/ft^2-hr-F°, while volumetric heat capacity was set at 4.0 Btu/gal-F°. Exchangers are single-pass, counter-current with fixed-tube sheets and of carbon steel. The more contaminated oil should be assumed on the tube side in the exchanger to minimize maintenance problems. Operating pressures are expected to be in the 150 to 200 psig range and heat transfer at about 425,000 Btu/hr.

Given volumetric flows of 25,500 gallons per day, I1 should have a tube area of about 350 ft^2. This is a fairly small heat exchanger whose cost must be adjusted accordingly for a 300 psig pressure rating.

Process Heater (F1) --

This heater or furnace serves to heat the exiting feed oil from I1 to a temperature (about 450°F) suitable for stripping in the following flash tower. In essence, the process heater must: 1) heat the feed stock, 2) provide energy sufficient to vaporize water, light-ends or naphtha, and non-condensibles, and 3) make-up the heat lost from the following flash tower and piping (estimated at about 10 percent of the heat input.) Given the 25,500 gallons per day flow, these factors demand a total heat output of about 1,000,000 Btu/hour. About 10 percent of this output is due to vaporization of approximately 7.5 gallons per hour of water and 18 gallons per hour of naphtha.

Now, for preliminary purposes, the maximum temperature differential across the furnace was set at 75°F, and the recycle-to-feed ratio for the furnace/flash tower loop was set at 2:1. In addition, a design goal of "reasonable" startup time at something like two hours was also specified. With these constraints, F1 must have a heating capacity of about 1,500,000 Btu/hour which provides about 30 percent excess capacity for steady-state operations. For preliminary purposes this furnace should be assumed a direct fixed-tube heater with allowance made for its relatively small size.

Flash Tower (FT1) --

This tower was sized based on a projected maximum throughput of 15 percent over nominal or 29,300 gallons per day and a mean liquid residence time of about 30 minutes based on existing re-refining practice. The tower should contain a single sieve tray to serve essentially as a splash plate; construction should be of carbon steel for about a 5 psig operating pressure. Complete fittings should be supplied with the column including ports for extensive sampling capability. The tower should also be insulated to cut down on heat losses which place an additional burden on the process heater, F1.

Now, the residence time and flow rate called out above imply a liquid holding volume in the tower of about 120 ft^3, including an allowance for thermal expansion. Vapor release rates (relative to liquid volumetric flow) in the column are very low (about 0.1 ft/sec.); vapor velocity is, therefore, not limiting in this tower design. To provide a manageable tower height, a four-foot diameter should be adequate although the consequent vapor movement in the tower will probably be pulsating which is of little concern for a flash or continuous pot distillation. Given the above criteria, plus 2-1/2 feet for splash plate clearance and 6 feet as vapor space, the flash tower should be about 18 feet tall. Cost estimates based on this sizing estimate should include the splash plate plus a spare, basic fittings, insulation, and a charge for servicability hardware (nozzles, ports, manholes, etc.).

Air Cooler (AC2) --

Due to the extremely low vapor rate from the flash tower, very little condensation service is necessary for overhead water vapor and naphtha. Initial estimates are that, for the quantities of condensibles involved (See the above section on F1), a 15-ft^2 air cooler should be adequate;

this is a very small piece of hardware, and the implication is that natural convection cooling may be adequate. However, recognizing that controlled condensing is necessary, air coolers have been included in the design for preliminary purposes. Again, a zero-degree temperature approach was assumed for air coolers as well as 20-foot tubes, 150 psig operation and automatic adjustment of blade pitch. Since non-condensibles comprise only a very small portion of the overheads from FT1, overall heat transfer coefficients of 70 and 135 Btu/ft^2-hr-F° were assumed for naphtha and water, respectively. Maximum ambient air temperature for the Central Maryland area was set at 100°F with basically a 95 percent expectation. Exit air and condensed liquid temperatures were set at 120°F. Heat transfer is about 120,000 Btu/hr.

Gravity Separator (S1) --

Condensed overheads from the flash tower must be separated, at least crudely, into water, naphtha and non-condensible fractions. A baffled horizontal tank is suitable for this task if provided with piping, valves, sight glass, access ports and vents. Since the nominal flow to the separator is only about 30 gallons per hour (projected maximum of 180), a very small (say, about 275-gallon) tank will suffice. This is almost a negligible hardware requirement in terms of cost.

Process Heater (F2) --

The same general comments hold for this furnace as for F1 discussed previously. Throughput is, however, significantly higher since some oil from the solvent extraction subsection and some recycled product will be subjected to the adsorbent treatment for which F2 supplies heat. Net feed to the furnace/adsorption loop is about 33,000 gallons per day. This heater nominally increases the process oil temperature only 100°F. Therefore, the total heating requirement is relatively small: about 870,000 Btu/hour of which only about 8 percent is due to vaporization of additional naphtha and reaction products in the contactor. On the other hand, a 1-1/2 to 2 hour startup requirement (due to the large amount of oil which is held in the adsorption contact column) demands a relatively large heat output from F2; 5,700,000 Btu/hour is required which represents a 450 percent excess over steady-state operations. Final design must seriously consider the feasibility of a longer startup period which may fit in reasonably with operating plans. In line with this possible approach, a single, two-chamber, direct-fired heater could increase the capital investment by about 30 percent. This would, however, tend to couple operation of the flash tower, FT1, and the contact tower which, in turn, could have a detrimental effect on plant flexibility.

Adsorbent Contact Column (CC1) --

Net flow to the adsorption column is the same as that to F2. Although residence time for contacting is of primary concern in sizing an adsorbent contactor, foam generation demands a considerable increase in contact column size; this phenomena is due primarily to catalytic reaction of the waste oil on the adsorbent which releases relatively light vapors. A nominal residence time for oil-adsorbent contacting of 1-1/2 hours yields a contactor volume requirement of 240 ft^3 including an allowance for thermal expansion to 550°F. On a batch basis, foam generation has been observed in the laboratory to be approximately as follows: 1) maximum foam volume is reached 5 minutes after contacting is initiated and is about equal to the volume of the waste oil generating the foam, and 2) from 5 to 30 minutes after initial contact foam volume decreases from the maximum to essentially zero. Considering conditions of a maximum expected oil throughput and minimum residence time then leads to a maximum expected foam volume of about 33 percent of the liquid volume. This estimate is based on plug flow through the contactor and is, therefore, conservative since all foam-generating oil remains in the reactor as long as the residence time is over 30 minutes.

Now, the adsorbent contact column should also contain a sieve tray to serve as a splash plate; as with the flash towers, about 2-1/2 feet clearance must be provided in the column for this item. Assuming a 6-foot diameter, about 15 and 5 feet of column height are required for liquid and foam volumes, respectively; an additional 6 feet should be supplied as a vapor release space at the top of the column. Therefore, the contact column should be about 28-1/2 feet tall. Construction of carbon steel for a 150 psig operating pressure should be adequate. A spare sieve tray should be supplied with the column as well as fittings, manholes and sampling ports. Again, this column should be well-insulated and suitable for steam stripping or vacuum service.

Air Cooler (AC3) and Gravity Separator (S2) --

Both the cooler and separator which must be supplied to accept the overheads from the adsorbent contact column are essentially identical to the similar items associated with FT1. The primary difference will be a slightly greater throughput and very, very much less water condensed and separated. For preliminary design purposes, AC3/S2 can be considered equivalent to AC2/S1. Heat transfer is about 95,000 Btu/hr. In a final design, this equipment may be entirely eliminated and the overheads sent direct to incineration through a flash arrestor.

Naphtha Holding Tanks (T12A and T12B) --

The organic fraction of the condensed overheads from the flash towers and contact column must be stored for disposal or use as a solvent. Since this naphtha-like material may itself have to be re-refined before being used as a solvent, two storage tanks are required: one to receive naphtha directly from the plant's separators and the other to hold the naphtha after it has been polished. Tanks of 10,000 and 20,000 gallons are required for these two functions, respectively.

Adsorbent Feeder (SF1) and Belt Conveyor (BC1) --

Since adsorbent is a very significant operating cost element and contacting must be carefully controlled to be successful, adsorbent must be fed in a controlled manner to the contact column. Bulk adsorbent should be fed (at about 400 pounds per hour) in a very positive fashion to an agitated tank where it is slurried with oil. The resulting slurry must, in turn, be metered to the contact column. A vibrating screen and hopper should be supplied to receive fresh adsorbent; a variable-speed conveyor belt should remove adsorbent from the hopper and deliver it to the agitated slurry tank. This tank should be relatively highly powered to assure complete mixing and dispersion; adsorbent/oil slurry from the tank will be metered to the contact column preferably based on level control of the tank contents. That is, the basic adsorbent feed rate (about 3-1/2 tons per day) must be controlled by the belt feeder. A 90 to 100-ft^3 feed hopper and 200- or 300-gallon agitated tank should provide enough capacity for day-to-day operation of this subsystem.

Air Cooler (AC4) --

The waste oil/adsorbent slurry from the contact column must be cooled to about 400°F before rotary precoat filtration. Again, to avoid cooling water discharge problems, an air cooler can be used for this task. Using general criteria as for AC2, an air cooler with about 210 ft^2 of tube surface is required; this is a moderate-sized cooler so that no question arises as to the feasibility of natural convection cooling. Heat transfer of about 900,000 Btu/hr. is required.

Rotary Precoat Filters (RF1 and RF2) --

Vacuum precoat filters have been used in the waste oil re-refining industry, although perhaps not to the degree which might be expected. Unfortunately, available information indicates that filtration rates are considerably lower than usually observed in the process industries. For example, 20 to 50 gallons per square foot-hour is often expected, but Dorr-Oliver has determined 11 gallons per square foot-hour as a possibility and 7 gallons per square foot-hour as a reasonable design rate. That is, rotary precoat filtration provides only about a sixth of the throughput expected from pressure filtration of waste oils. Now, to maintain steady-state operation, two filters will be necessary; that is, while one filter is operating, the other will be in preparation. Total feed to the filter subsystem is estimated to be 37,200 gallons per day; with a 15 percent safety factor, this implies filters of about 250 ft^2 or approximately 8 feet in diameter and 12 feet long. Final design should consider the possibility of using a single oversize filter recognizing that this could limit the process rate of the whole adsorbent treatment subsection to that of the filter. Carbon steel construction should be adequate for this item. Special venting will be required to assure that vapors generated by the operation (especially during precoating) are sent to the plant's incinerators. Controls should also be included to assure semi-automatic operation.

Air Cooler (A1) --

The main product stream from the adsorbent treatment subsection should be cooled somewhat before being sent to storage or users. Air cooler AC1 reduces the temperature of the product oil from I1 an additional 100F°. A decreased mean temperature difference as compared to AC4 (89 versus 216°F) accounts for this cooler being about the same size even though throughput is lower. Heat transfer is 425,000 Btu/hr in cooling the oil from 300 to 200°F.

Solvent Extraction Subsection

This section of the plant is considerably simpler than the adsorbent subsection since it serves essentially as a support process. Primary feed to solvent extraction is estimated at about 22,800 gallons per day; this flow includes a bottoms stream which is stripped to recover solvent. Waste oils requiring both adjusted and special processing are routed to the solvent extraction subsection: 12,600 gallons per day due to the former and 8,400 due to the latter. For flexibility of design, a portion of the adjustably processable oil is sent to adsorbent treatment either without (5,100 gallons per day) or after (4,500 gallons per day) solvent extraction. As with the adsorbent treatment, feed to this plant subsection must first have BS&W (about 3,450 gallons per day) removed by settling; then, naphtha and water must be stripped from the stock. The resulting waste oil is sent to either adsorbent or solvent treatment. The following paragraphs briefly describe the unit operations of this plant subsection.

Heat Exchanger (I2) --

The function of this exchanger is analogous to I1's: feed oil is heated and product oil cooled. The discussion of heat exchanger I1 should be referred to for general preliminary design criteria. Although temperature requirements are essentially the same, the lower throughput dictates a somewhat smaller exchanger: about 290 ft^2. Note that the entire heat exchanger/furnace/flash tower loop of the solvent extraction subsection can serve as a backup to the similar adsorbent treatment loop, albeit at a slightly reduced flow. Heat transfer is at about 430,000 Btu/hr with a log mean temperature difference of about 120F°.

Process Heater (F2) --

Although the waste oil flow is less than to F1, the requirement for vaporization of more naphtha and water sets F2 at about the same size at steady-state: 1,100,000 Btu/hr. However, possible emulsion breaking necessitates a higher liquid residence time in the following flash tower. That is, the amount of oil FT2 contains is considerably larger than for FT1; this, in turn, imposes a more severe startup requirement. If 1-1/2 hours' startup time is required, F2 must have a heating capacity of

2,700,000 Btu/hr; this is a 150 percent excess as compared to steady-state operation. The other general preliminary design criteria are the same as for F1. Again, final design should seriously consider increasing the startup time called out above as a means of decreasing the size of F2.

Flash Tower (FT2) --

The general preliminary design requirements for FT2 are the same as for FT1. Greater flexibility for thermal emulsion breaking is supplied by setting the liquid residence time at 65 minutes as compared to 30 minutes for FT1; this sets the liquid volume at about 20 ft^3 including allowance for thermal expansion to 450°F. The entire 4-foot diameter tower should be about 22-1/2 feet tall: 16 feet for liquid holding, 2-1/2 feet for splash plate clearance, and 6 feet for vapor space. Again, a spare splash plate, manholes, sampling ports and extensive insulation should be supplied with the tower. The tower's vapor velocity is also very low in this case: about 0.3 ft/sec.

Air Cooler (AC7) and Gravity Separator (S3) --

Although somewhat larger than AC2, the air cooler to condense the overheads from FT2 is still a small unit; for preliminary design purposes, AC7 and AC2 may be considered equivalent. The separator, S3, which accepts the condensed liquids from AC7 is similar to S1. Again, a small, properly baffled and fitted horizontal tank should serve for this duty. Only an average 25 gallons of water and 42 gallons of naphtha have to be separated per hour. General preliminary design criteria for AC7 and S3 have been discussed in previous paragraphs. Heat transfer by AC7 is about 350,000 Btu/hr.

Air Cooler (AC6) --

Of the processed oil which leaves FT2, only 14,700 gallons per day is actually sent to the solvent extractors; after passing through I2, this oil must be cooled even further to prevent solvent vaporization. As a first approximation, 110°F was selected as the design temperature for oil going to solvent extraction. The oil from I2 will be at about 325°F. Using the same general design criteria as for the other air coolers, a log mean temperature difference of 153°F is implied, and AC6 must have about 170 ft^2 of projected tube surface. As with AC4, this is a moderate size air cooler and natural convection cooling is out of the question. Using the above and general specifications as for AC1, cost estimates for AC6 can be developed. Heat exchange required is about 525,000 Btu/hr.

Solvent Extraction Tanks (AT1 and AT2) --

Since little operational data exists on full-scale solvent extraction of waste oils, preliminary design aimed in this direction must be very flexible. Possible solvents, solvent-to-oil ratio, contact times and settling times must be specified in a conservative fashion. Preliminary estimates are that 14,700 gallons of waste oil will be treated by solvent extraction each day. Now, for fuel oil production, fairly moderate solvent-to-oil ratios may be feasible although this is known not to be the case for lube oil production. As a nominal design condition, therefore, a solvent-to-oil ratio of 1.5:1 has been selected. It must be recognized, however, that at least in special cases, ratios of 4:1 or 5:1 may be required; such increased ratios would, in turn, decrease solvent extractor capacity by 40 to 50 percent. Given conservative enough estimates, such a decrease of capacity should not critically limit plant operation.

Given the nominal waste oil and solvent rates of 14,700 and 22,000 gallons per day, respectively, solvent extractors can be sized. Due to the "custom" processing nature of solvent extraction in the proposed plant, batch processing has been selected for preliminary purposes. Two extractors plus extract and sludge holding tanks are required to maintain a flexible semi-continuous operation. Assuming a single turnover of each extractor per shift, 6,200 gallons of capacity is required. With a 15 percent safety factor, each extractor must hold about 950 ft^3. In addition to holding solvent/oil mixtures, the extractors must have agitation and cooling capabilities; insulation should also be provided. Agitators should be of variable speed to permit control over both degree of contact and emulsion formation; low-energy, paddle-type agitators are preferred. Carbon steel construction for 150 psig rating should be adequate. As with many of the other items in the proposed plant, venting to the waste incinerators must be provided as well as access, sampling and control ports.

Solvent Holding Tank (T11) --

Assuming use of a single solvent and continuous solvent recovery from the extract phase, one day's solvent requirement (22,000 gallons) held for feed to the solvent extractors should be adequate. Solvent holding tank, T11, should also be of carbon steel construction and suitable for light naphtha service; again, complete venting, sampling, and access ports should be supplied.

Extraction Bottoms Tank (T9) --

Preliminary estimates are that 1,860 gallons per day of bottoms or sludge will result from solvent extraction. Assuming 5 days' operation before bottoms are stripped to recover residual solvent, a holding tank of about 9,500 gallons is required. Of the same general specifications as T11, this holding tank should have a cone bottom and outlet port to assure complete drainage.

Solvent Extract Tank (T10) --

The largest portion of the effluent from the solvent extractors is expected to be the solution of solvent and oil. A tank must be supplied to accept and hold this mixture prior to separation and recovery of solvent and oil by stripping. Since the largest portion of the plant's solvent will be in the extract stream (total flow of 35,100 gallons per day), solvent stripping must keep the pace in order to hold down solvent inventory. In the worst operational case imaginable, both solvent extractors would be dumped simultaneously; that is, 11,700 gallons of solvent/oil mixture might have to be placed in T10 at once. Allowing 1/3 as a safety factor, a 15,500-gallon tank should, therefore, serve for this operation. Other tank specifications should be essentially as for T11.

Process Heater (F4) --

The extract phase from the solvent extractors must be stripped for solvent and oil recovery. Assuming a light naphtha solvent for preliminary design purposes, about 3,100,000 Btu/hr are necessary to heat the charge and vaporize the solvent. A 1-1/2-hour startup (as was the case for the other process heaters), on the other hand, necessitates 4,700,000 Btu/hr which is about 50 percent in excess of steady-state demand. This is reasonable enough for a preliminary design estimate. Other heater specifications are substantially the same as for F1. The solvent/oil mixture to this heater will be at 110°F and the exit stream at about 400°F.

Fractionating Column (FC1) --

Approximately 21,600 gallons per day of solvent must be recovered from the waste oil extract stream. Since the waste oil has previously been "dehydrated" to about 450°F, solvent recovery is really a matter of stripping. With a reasonably volatile solvent (say, light naphtha) distillation to about 400°F should be adequate for solvent recovery without substantial oil carryover. For preliminary design purposes, a light naphtha solvent of molecular weight 120, liquid density 7.1 pounds per gallon and normal boiling point 290°F was selected. Such a petroleum substance has a vapor density of about 1/4-lb/ft^3 at 290°F. Conventional limits on superficial vapor velocity were used to obtain a first estimate of fractionating column diameter; the upper limit serves to prevent entrainment of liquid and the lower column flooding. For the unit operation in question, the result was a 30-inch column diameter with a superficial vapor velocity of about 1.5 ft/sec. and a liquid to gas ratio of about 3. To provide limited stripping/rectification capability in the column, fractionating trays should be included; four such trays with 100 bubble caps per tray and 24-inch spacing were selected for preliminary design purposes. Average liquid residence time in the column was set at 30 minutes.

The height of the fractionating column should be about 20 feet: 5, 6, and 9 feet for vapor, tray, and liquid holding space, respectively. Spare trays should be provided for the column to provide continuing operation in conjunction with routine maintenance. As with the other columns in the plant, insulation should be provided and carbon steel construction should be adequate. Ports and nozzles should also be supplied as well as manholes to enhance servicing. A receiver of about 250-gallon capacity should be included to accept condensed solvent and to provide solvent recycle to the column at about 4 gallons per minute.

Air Cooler (AC9) --

Air cooling should be used to condense the overheads from FC1; this will eliminate a potential large cooling water demand on the plant. Given the general specifications and conditions as for AC1, this air condensor should have a tube surface area of 535 ft^2 which includes allowance for solvent recycle of about 20 percent of the net overheads from FC1. Thus, AC9 is the largest air cooler projected for use in the plant involving about 1.5 million Btu/hr of heat transfer based on cooling (and condensing) the FC1 overheads from 290 to 120°F with a heat transfer coefficient of 70 Btu/ft^2-hr-F°.

Product Air Coolers (AC5, AC8, and AC10) --

Three product streams exit from the solvent extraction subsection of the plant. One will be subjected to clay treatment after stripping, another after solvent extraction, and another not at all. These streams must be cooled (by AC5, AC8, and AC10, respectively) to a temperature suitable for storage, about 200°F. Each of these air coolers is a small unit and, given the same general specifications, may be considered equivalent to AC1 for preliminary design purposes. Heat transfer rates of about 90, 160, and 290 thousand Btu/hr are required of each of these coolers, respectively.

Incineration Subsection

Waste oils which cannot or should not be re-refined must still be handled by the proposed comprehensive processing facility. Furthermore, the various re-refining operations themselves generate oily wastes which must be disposed of. Preliminary design of the tank farm and other re-refining facilities has already considered non-recoverable waste oils and in-plant oily wastes. Ultimate disposal must still be accounted for, however. A relatively complex plant subsection for destruction of waste oils, sludges, spent absorbent and other materials as well as recovery and isolation of contaminants has, therefore, been developed conceptually. Three incinerators are suggested for comprehensive waste disposal:

1. A Rotary Hearth Kiln for solids,
2. An Incinerator for routine liquid destruction, and
3. A very carefully Controlled Incineration Subsystem for disposal of highly contaminated liquid wastes.

Clay Incineration Kiln (K1) --

Whether or not clay is used for adsorbent treatment, waste oily solids will be generated at the proposed facility. The most positive way to incinerate solids is to use a rotary or multiple hearth kiln. Of course, other methods could also be used; fluidized bed incineration is a prime example. However, the expected high variability of solid wastes both generated by the plant and sent to the plant for disposal weighs heavily in favor of a very positive mechanical assist to the combustion process as opposed to fluidization. With this in mind, a multiple hearth kiln or furnace was selected for preliminary design purposes. First estimates are that about 4-1/2 tons of waste adsorbent will have to be incinerated each day including some oil. Waste oil or recovered naphtha will also be burned in the kiln, mainly as an assist to combustion. Using a design rate of 2-1/2 lbs/ft^2-hr and a 20 percent safety factor, a kiln with a grate area of about 185 ft^2 is required; given, say, 4 tiers, this is equivalent to an 8-foot diameter kiln which is relatively small. A 10-foot diameter kiln with 311-ft^2 grate area is the standard size nearest to this mentioned in the literature and, therefore, should be used for preliminary design purposes. The maximum instantaneous capacity for such a kiln would be about 750 lbs/hr, which should be sufficient to allow for downtime and extraordinary operating days. Construction should be of carbon steel and fire brick and includes venting, sampling, control, access ports, and auxillary burners.

Routine Incinerator (IN1) --

Some waste oils will be incinerated directly since they will present minimum air pollution problems. First estimates are that about 6,600 gallons will be burned per day resulting in the release of about 9 x 10^8 Btu. This oil will, by definition, be low in halogen and sulfate components as well as particulate matter, and therefore, stack gases from the incinerator should be subjected to only very crude dust removel, if at all. Carbon steel/firebrick construction should be adequate. An air blower should be included as an integral part of the unit as well as an appropriately-sized stack. It should also be fitted for steam injection of wastes in order to provide increased operating flexibility. IN1 will be a chamber-type incinerator with spray nozzle injection.

Controlled Incinerator (IN2) --

Certain waste oils and oily wastes generated in the plant will have to be incinerated and will contain high loadings of sulfur, halogens, and metallic particulates. Contaminant recovery from IN2's effluent gases will, therefore, be absolutely necessary. Preliminary estimates are that approximately 15,600 gallons of waste oil and 2,800 pounds of vapors will have to be burned daily in this incinerator. This material should release about 16 x 10^8 Btu upon combustion.

Although the general specifications for IN2 will be similar to those for IN1, considerable care will have to be taken in selecting materials of construction to avoid attack by acid gases or heavy metal particulates. The exit gases from IN2 will contain sulfur dioxide, hydrogen halides, and heavy metal particulates as the primary contaminants. The preliminary design being presented here considers scrubbing of these contaminants with selective recovery; the recovered materials will, obviously, not be of high purity. The exit gas rate from IN2 is estimated at about 17,100 SCFM. A pair of venturi scurbbers will first remove the particulates and then the acid gases. Clarification, filtration, and drying will then be used to recover a heavy metals sludge, calcium halides, and calcium sulfate. IN2 will also be a chamber-type incinerator with spray nozzle injection.

Particulates Venturi Scrubber (VS1) --

Heavy metal particulates will first be scrubbed from IN2's exit gases; since these gases will contain SO_2 and CaX_2, particulate scrubbing will take place under acidic conditions at about 200°F. A major portion of the make-up water for the incineration subsection will be added at this scrubber. Although a venturi scrubber has been specified for the purpose of preliminary design, the particulates in the gas may be so small (something like 90 percent by weight less than one micron) that this approach will not be successful; in this case, a baghouse, electrostatic precipitator or absolute filter would have to be used. This may, in fact, turn out to have to be the case. Due to the acidic conditions, construction should be of lined carbon steel. Since this scrubber will be removing very small particles, it will have to be a high energy device; that is, the pressure drop across the scrubber will be high (something like 50 inches of water) and considerable power will be required (on the order of 200 to 300 horsepower). Note that use of one of the other devices mentioned above could lead to a significant increase in capital and operating costs for the operation in question.

Particulates Clarifier (CL1) --

The slurry from VS1 must be clarified before recycling the water and dewatering the particulates. Due to the expected small size of the particulates, flocculation and conditioning of the slurry to the clarifier will be necessary; a reactor/clarifier is, therefore, actually the unit operation required. A flash mixing tank for addition of 50 percent sodium hydroxide solution should be placed ahead of the reactor/clarifier; flocculating polymer should be added to the slurry just before the reaction chamber. Slurry flow rate through the reactor/clarifier should be about 33 gpm; approximately 12 gpm of this will be underflow with about 5% solids. The remaining 21 gpm of overflow will be sent to clarifier CL2 and eventually to the acidic gas scrubber, VS2. Since clarification will take place under conditions of high pH, carbon ssteel construction should beaadequate.

Acid Gas Venturi Scrubber (VS2) --

Exit gases from VS1 will contain sulfur dioxide and hydrogen halides as the primary contaminants. These acidic compounds will be removed from the gas stream with a venturi scrubber using aqueous calcium hydroxide. Although the general specifications for this scrubber are similar to those for VS1, adsorption will take place at high pH and lower temperature (estimated at about 150°F); carbon steel construction should, therefore, be adequate for this unit operation. Again, throughput will be about 17,100 SCFM.

Lime Slaker (SL1) --

Preparation of the caustic solution for use in VS2 will require approximately 2.3 tons per day of lime. This is a sufficient quantity to make it feasible to slake lime at the process facility as opposed to purchasing same. Provision should, therefore, be made in the proposed facility to slake about 3.0 tons per day of 92 percent CaO.

Acid Salts Clarifier (CL2) --

The lime solution from SL1 as well as the blowdown from VS2 will be mixed and sent to reactor/clarifier CL2. Flocculating polymer should be added before CL2 to assist in dropping out calcium sulfate. Total feed to CL2 will be about 50 gpm containing suspended $CaSO_4$ and dissolved $CaCl_2$ (i.e., calcium halides). About half this quantity will be underflow from CL2 containing about 2 percent $CaSO_4$ by weight. The reactor/clarifier's overflow will be split into two parts: about 10 percent blowdown which will be sent to a spray drier for $CaCl_2$ recovery and the remaining 90 percent recycled to VS2. Calcium sulfate underflow and calcium halide blowdown are estimated at about 2.4 and 2.6 tons per day, respectively.

Spray Drier (DR1) --

The blowdown from CL2 will contain 20 to 25 percent by weight $CaCl_2$ in a total volumetric flow of about 2-1/2 gallons per minute. Spray drier, DR1, will utilize hot flue gas from I2 to evaporate the water in this stream yielding about 2.6 tons per day of "dry" $CaCl_2$. Due to potentially very corrosive conditions, this equipment should be suitably lined, possibly with ceramic. Operation of DR1 should be essentially automatic and, therefore, pertinent controls, etc., should be supplied with the unit.

Sludge Storage Tanks (PS1 and PS2) --

Since the metallic particulates and precipitated $CaSO_4$ will both be concentrated by vacuum filtration using the same unit, intermediate storage or holding tanks will be required. Based on the flow rates already indicated, 39,000- and 22,000-gallon tanks are required for the two sludges, respectively. Due to corrosive conditions, especially in the first instance, these tanks should be epoxy lined carbon steel. In addition, the tanks should be covered and fitted with appropriate sampling, control, and vent ports.

Rotary Filter (RF3) --

The sludges just mentioned will be filtered for recovery of metallic particulates and $CaSO_4$ solids. A rotary precoat vacuum filter should be used for this task and have the same general specifications as for RF1/RF2. However, corrosive conditions mandate that this filter be constructed of 304 stainless steel or an equivalent. Another important difference is that the basic liquid filtered by RF3 will be water; throughput, therefore, will be relatively higher. A conservative design base of 25 gal/ft^2-hr leads to a filter area of about 100 ft^2 which should be adequate for preliminary design purposes. About 5.5 tons of solids will be recovered each day from a feed stream of about 37 gallons per minute to this unit.

LAND REQUIREMENTS

Land for the proposed waste oil processing facility must be allocated to seven basic plant elements:

1. Tank Farm, including Primary Waste Oil Storage Reactor/Settler and Holding and Product Storage Tanks,
2. Receiving Tankage,
3. Adsorbent Treatment Subsection,
4. Solvent Treatment Subsection,
5. Incineration Subsection,
6. Plant Buildings and Parking Space, and
7. Road and Rail Access.

Table 11 on the following page lists the preliminary land estimates for these elements.

MASS BALANCES

Table 11 gives a summary mass balance for the full-scale process plant, excluding the incinerator subsection. This subsection is not included since it serves for ultimate disposal of other process residues. The basic equipment discussions of Section V contained estimates of the more critical flows for the two incineration loops. These summary figures are the result of more complete and detailed balances performed while characterizing the entire process plant. The more significant heating and cooling requirements for the process plant are also presented in Section V.

Table 11. LAND AREA REQUIREMENTS

Plant Element	Area (acres)
Tank Farm	3.7
Receiving Tankage	0.2
Adsorbent Treatment Subsection	0.7
Solvent Treatment Subsection	0.8
Incineration Subsection	0.8
Plant Buildings and Parking	0.5
Road and Rail Access	1.2
Expansion and Outdoor Storage	0.6
Subsection and Plant Clearance	4.5
TOTAL	13.0

Table 12 presents volumetric flow values for the 83 flow streams which are numbered on the basic process flow sheet (page 37). Due to the small (by mass and volume) amounts of water, volatiles, and solid contaminants present in waste oil, these volumetric flows represent an overall balance of sufficient accuracy for preliminary design purposes. Included to illustrate this sufficiency, are estimates of the probable error in each of the 83 flow streams.

PROCESS INSTRUMENTATION

The list below indicates the degree of instrumentation required for the proposed full-scale facility. As presently conceived, the basic instrumentation is quite simple: flow, temperature, level, speed, pH, and density controllers. This can be misleading, however, since extensive process analytical services have been assumed in setting instrumentation requirements.

Type Controller	Number
Flow	28
Temperature	27
Level	20
Speed	1
pH	2
Density	2
TOTAL	80

EQUIPMENT COST ESTIMATES

The following pages contain a tabulated summary of preliminary cost estimates for the process equipment discussed in the previous sections. These estimates are arranged in four groups corresponding to the four major processing subsections. It should be noted that the incineration subsection requires a large portion of the total capital cost which should even be larger if more sophisticated air pollution control systems eventually prove necessary (e.g., a baghouse as opposed to a venturi scrubber for particulates removal). The other major (in terms of cost) subsection is represented by the reactor/settler tank; final design should devote considerable effort in an attempt to reduce its cost. For instance, if standard carbon steel tankage could be used for this purpose as opposed to agitated, heater reactor, a major cost savings would be won. The adsorption treatment and solvent extraction subsections are nominal in terms of relative cost and, therefore, cannot be the object of major cost savings efforts in a direct fashion. For detail on the equipment items of Table 13, the reader is referred to the previous section, Equipment Requirements.

The equipment cost estimates presented here are used in Section VIII of this design report for the development of a preliminary capital cost estimate for the entire process plant.

Table 12. PROCESS FLOWS AND POSSIBLE VARIATIONS FOR ALL MAJOR PROCESS STREAMS AS IN FIGURE 3 *

Stream Number	Flow (GPD)**	Possible Variation (% Higher/% Lower)
1	16,200	10/35
2	10,800	10/35
3	14,700	50/10
4	9,300	60/20
5	750	50/50
6	60	100/100
7	60	100/100
8	60	100/100
9	240	100/100
10	20	100/100
11	40	100/100
12	15,000	15/35
13	10,000	15/45
14	12,600	80/50
15	8,400	75/35
16	25,500	15/40
17	24,900	20/50
18	5,100	85/80
19	35,700	75/60
20	2,700	20/50
21	33,000	85/70
22	180	400/95
23	420	500/95
24	6	500/95
25	34,500	90/75
26	66	195/100
27	690	195/55
28	6	195/55
29	1,800	760/95
30	3.6 TPD solids	360/85
31	37,200	85/75
32	0.2 TPD solids	200/85
33	2,130	540/85
34	960	300/100
35	0	-

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* Due to the lack of commercial and other data, the incineration subsection is not included.

** Other units, where pertinent, are called out; values at standard temperature and pressure.

Table 12 (Continued). PROCESS FLOWS AND POSSIBLE VARIATIONS FOR ALL MAJOR PROCESS STREAMS AS IN FIGURE 3 *

Stream Number	Flow (GPD)**	Possible Variation (% Higher/% Lower)
36	1,140	400/85
37	36,900	85/80
38	35,700	75/80
39	17.0	730/90
	3.9 TPD solids	260/85
40	1,170	430/90
41	600	500/100
42	840	4900/100
43	250	320/90
44	0	-
45	25,500	55/70
46	22,800	170/55
47	21,000	190/80
48	600	4800/100
49	1,020	770/95
50	22	2250/95
51	5,400	140/85
52	20,100	80/80
53	5,400	140/85
54	1,890	1000/95
55	1,350	1350/100
56	4,800	320/95
57	14,700	85/80
58	22,200	200/85
59	36,900	155/85
60	6,600	560/90
61	35,100	170/90
62	1,860	1000/95
63	0	-
64	0	-
65	540	500/95
66	300	200/85
67	35,100	170/90
68	13,200	120/90
69	220	200/90
70	21,660	200/90
71	4,500	300/95
72	8,700	195/100
73	1,350	90/60
74	510	150/70
75	2,400	450/100
76	1,050	75/35
77	240	65/70
78	180	65/70
79	450	65/70
80	300	65/70
81	60	100/100
82	10,800	205/85
83	1,740	800/95

Table 13. PROCESS EQUIPMENT COST ESTIMATES BY PLANT SUBSECTION

Flowsheet Number	Item	Purchased Cost
	Reactor/Settler Tanks	
T1 & 2	Standard Processing-Crankcase Oils (30,000 gallons, each)	$ 96,800
T3 & 4	Standard Processing-Industrial Oils (20,000 gallons, each)	73,600
T5 & 6	Adjusted Processing (45,000 gallons, each)	132,200
T7 & 8	Special Processing (30,000 gallons, each)	96,800
R1	Caustic Reagent Tank (2,500 gallons)	2,100
R2-4,6,7	Misc. Reagent Tanks (275 gallons, each)	3,200
R5	Oxidizer Reagent Tank (1,000 gallons)	1,600
	SUBTOTAL - - - - - - - - - - -	$406,300
	Adsorbent Treatment	
I1	Heat Exchanger (350 square feet)	$ 3,900
F1	Process Heater (1.6×10^6 Btu/hour)	15,400
FT1	Flash Tower (4 x 18 ft.)	3,100
AC2	Air Cooler (100 square feet)	2,300
F2	Process Heater (5.7×10^6 Btu/hour)	25,500
CC1	Adsorption Contactor	6,600
AC3	Air Cooler (6 x 28.5 feet)	2,300
CT1	Adsorbent Addition Tank (30 gallons)	2,500
BC1/SF1	Adsorbent Feed System (550 pounds/hour)	4,000
AC4	Air Cooler (210 square feet)	4,100
RF1 & 2	Rotary Precoat Filters	67,800
AC1	Air Cooler (8 x 12 feet, each)	4,100
T12A & B	Naphtha Holding Tanks (10,000 and 20,000 gallons)	9,100
	SUBTOTAL - - - - - - - - - - -	$150,700

Table 13 (Continued). PROCESS EQUIPMENT COST ESTIMATES BY PLANT SUBSECTION

Flowsheet Number	Item	Purchased Cost
	Solvent Treatment	
I2	Heat Exchanger (290 square feet)	$ 3,500
F3	Process Heater (2.7 x 10^6 Btu/hour)	17,900
FT2	Flash Tower (4 x 22.5 feet)	3,700
AC7	Air Cooler (100 square feet)	2,300
AC6	Air Cooler (170 square feet)	3,400
AT1 & 2	Agitated Tank Reactors (7,100 gallons, each)	66,200
T11	Solvent Tank (22,000 gallons)	9,800
T9	Bottoms Tank (9,500 gallons)	6,500
T10	Extract Tank (15,500 gallons)	7,000
F4	Process Heater (4.7 x 10^6 Btu/hour)	22,600
FC1	Fractionating Column (2.5 x 20 feet)	3,900
AC9	Air Cooler (535 square feet)	7,600
AC5,8,10	Air Coolers (100 square feet, each)	6,900
	SUBTOTAL - - - - - - - - - -	$161,300
	Incineration	
BC2,3,4	Belt Conveyors (3.9 TPD, each)	$ 2,400
K1	Multiple Hearth Kiln (750 pounds/hour)	45,000
IN1	Routine Incinerator (9 x 10^8 Btu/hour)	73,500
IN2	Controlled Incinerator (16 x 10^8 Btu/day)	70,000
VS1	Particulates Scrubber (17,100 SCFM)	52,500
VS2	Acid Gas Scrubber (17,100 SCFM)	45,000
CL1	Particulates Clarifier (33 gpm)	7,900
CL2	Acid Salts Clarifier (51 gpm)	7,900
RF3	Rotary Filter (5.5 TPD)	34,000
PS1	Particulate Slurry Tank (39,000 gallons)	7,900
PS2	Gypsum Slurry Tank (22,000 gallons)	4,600
SL1	Slaker and Feed Hopper (9 TPD)	12,200
	SUBTOTAL - - - - - - - - - -	$362,900
	TOTAL - - - - - - - - - -	$1,080,000

SECTION VI

PRODUCT TANKAGE

INTRODUCTION

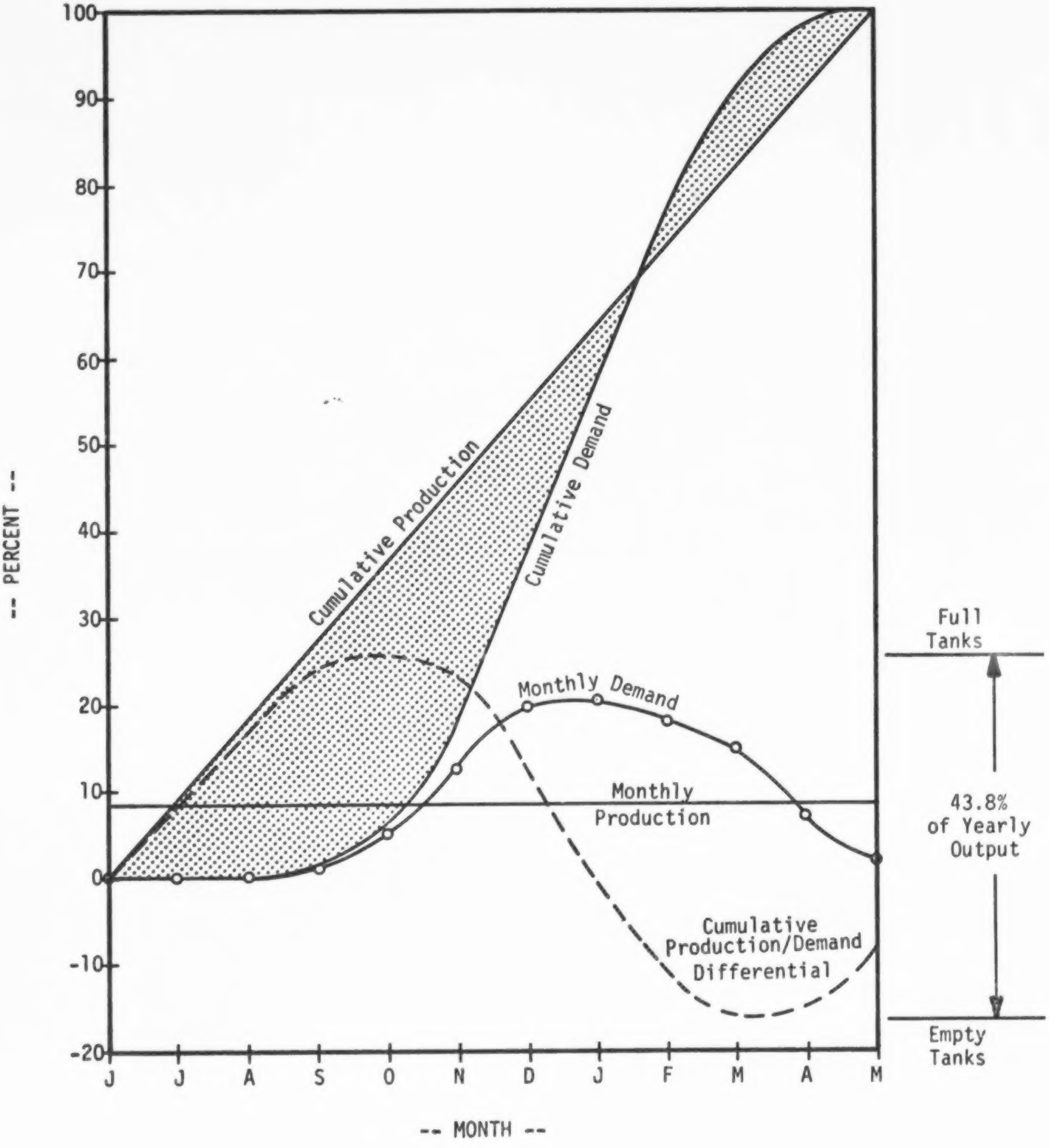
Product tank requirements are set mainly through product demand and variations thereof. Since the proposed facility will be used primarily for fuel oil production, seasonal demand for fuel oil should determine the necessary extent of product storage facilities. Although the State of Maryland may be the sole buyer for the plant's product, fuel oil demand in the Baltimore-Washington area should provide a reasonable base for preliminary design estimates. The table below summarizes fuel oil demand by month as a percentage of total yearly demand; this data is according to the Oil Heat Institute of Greater Washington.

Table 14. MONTHLY FUEL OIL DEMAND IN THE BALTIMORE-WASHINGTON AREA

Month		Percent of Yearly Demand
January		20.6
February		18.0
March		14.8
April		6.8
May		1.8
June		0.0
July		0.0
August		0.0
September		0.8
October		5.1
November		12.3
December		19.8
	TOTAL	100.00

Now, since the plant output depends primarily on the availability of feed waste oil, feed is much more constant than product demand because lubricating oil consumption is much more constant. That is, as was shown in the section on receiving tankage and primary waste oil storage, monthly variations in lube oil sales are at most 5 percent, which is negligible when compared to order of magnitude changes in produce demand. Figure 6, on the following page, illustrates this point graphically. Cumulative production by the proposed plant is plotted as a linear function: percentage of yearly production versus month. Monthly demand as percentage of yearly demand is also plotted; the data points for this curve came directly from Table 14. Cumulative demand follows directly from the monthly demand and is also presented in the figure.

Figure 6. PRODUCTION OF AND DEMAND FOR FUEL OILS - MES WASTE OIL FACILITY



Note that June was selected as the first month on the abscissa for convenience of graphical comparison and manipulation. The difference between cumulative production and demand represents the instantaneous storage requirement at any point in time. The storage requirement curve in the figure is just this difference; full storage tanks are indicated by the maximum of this curve in October while empty tanks are indicated by the minimum in March. The percentage span between the maximum and minimum represents the fixed storage required by the plant as a percentage of yearly production. This span is 44 percent. Using these results, Figure 7 is a plot of the percent of product storage in use by month; again, empty tanks in March and full tanks in October are indicated.

TANK REQUIREMENTS

As was presented in Section III, daily production for the proposed plant is estimated to be 40,700 gallons; then, based on 330 stream days, almost 14,000,000 gallons of fuel and lube base oils are produced each year. Assuming 25 percent cutter stock addition implies a total yearly production of 17,500,000 gallons. Allowing 10 percent as a safety factor implies that about 30 percent of this value must be devoted to product storage: 8,750,000 gallons. Table 15 tabulates State of Maryland fuel oil purchases for 1972 as well as number of State users, storage capacity, average yearly deliveries and average price per gallon. Note that Numbers 2 and 6 fuel oils are in predominant use. Now, the base oil product from the proposed processing facility will be similar to Number 5 fuel oil. Depending on the cutter stock used, oil viscosity can be adjusted upwards to that of Number 6 fuel oil or downwards to a Number 4 fuel oil which may be suitable for use in some installations which presently burn Number 2. Multiple or modified burner assemblies may be all that are necessary to accomplish this. Based on present allocations for State fuel oil storage and purchases, process plant main product storage tanks of 4, 0.75, and two of 2 million gallons are suitable for preliminary design purposes; these tanks correspond roughly to storage of Numbers 6, 5, 4, and 2 fuel oils (or their operational equivalent), respectively. Assuming quarterly delivery of cutter stock implies a cutter stock storage requirement of about 900,000 gallons; three 300,000-gallon storage tanks should be sufficient for preliminary purposes. Some automotive or base oil lube stocks will also be produced by the processing facility; for preliminary purposes, a 100,000- and two 50,000-gallon storage tanks are included for storing such products.

Basic costs and area requirements can now be developed for the product tankage. The 7 largest tanks would be carbon steel, floating roof, oil storage tanks of standard construction. The smaller tanks would be fixed roof as are the primary waste oil storage tanks. Table 16 summarizes the product tank requirements as just called out as well as preliminary estimates of installed costs and land area requirements.

Figure 7. PRODUCT FUEL OIL STORAGE AS A FUNCTION OF TIME

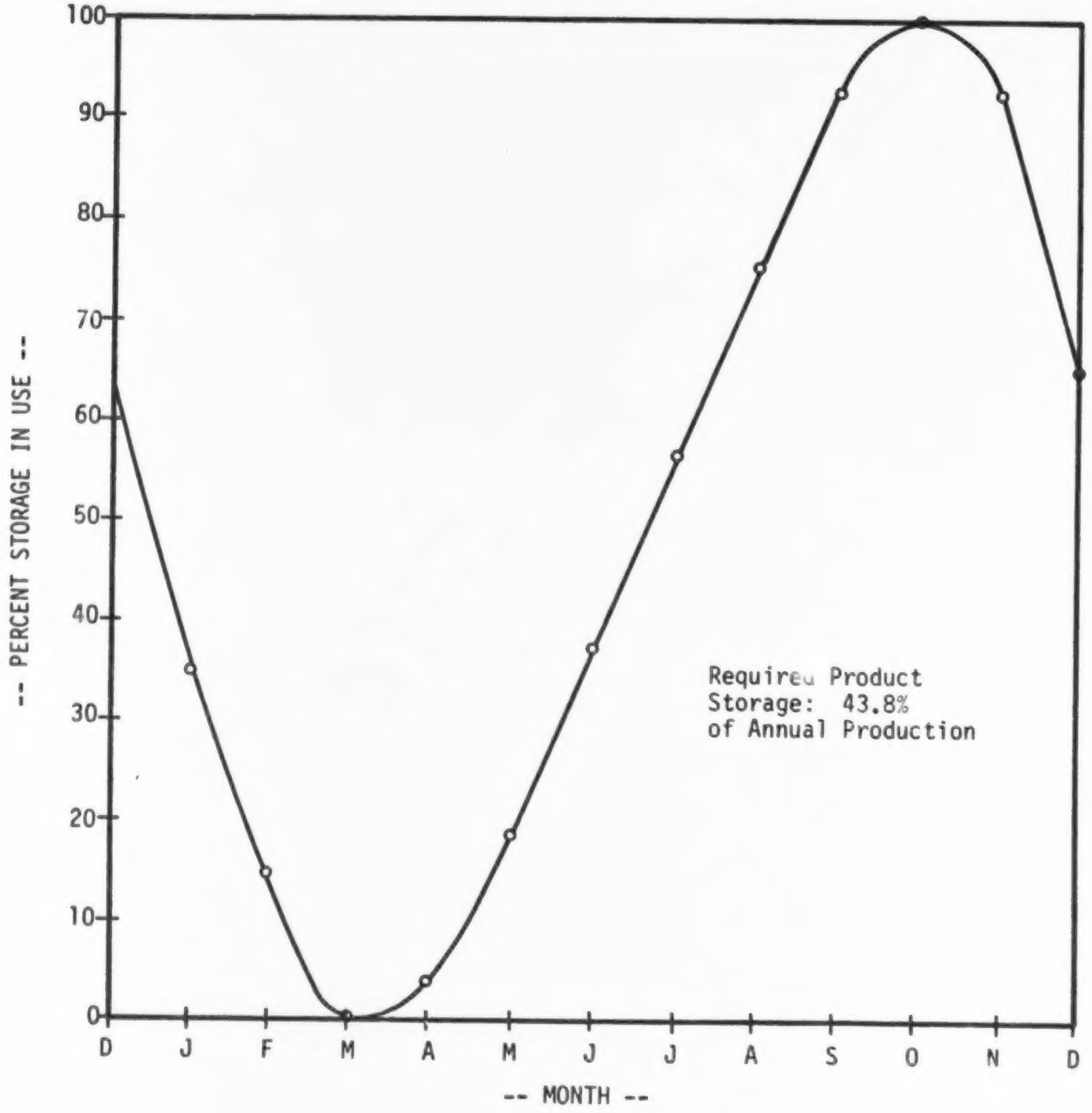


Table 15. STATE OF MARYLAND FUEL OIL PURCHASES FOR 1972

Fuel Oil Type	Number of State Users	Total Gallons Used	Storage Capacity (gal)	Deliveries Per Year (average)	Price Average (¢/gal)
1	31	82,400	17,380	6	17.33
2	266	13,046,850	2,079,643	8	13.85
5	6	455,000	96,000	6	12.12
6	12	14,383,000	1,039,000	21	10.33
Totals	315	27,967,250	3,232,023	--	---

Table 16. PRODUCT OIL TANK COST AND AREA ESTIMATES

Oil Category	Tank Volume (gallons)	Number of Tanks	Total Area Required (ft^2)	Total Cost Estimate
Lube Oil Base Stock	50,000	2	3,400	$ 29,200
Lube Oil Base Stock	100,000	1	2,700	21,300
Cutter Stock	300,000	3	16,800	92,700
Blended Fuel Oil*	750,000	1	10,000	50,200
Blended Fuel Oil	2,000,000	2	40,000	192,400
Blended Fuel Oil	4,000,000	1	32,000	147,000
	TOTALS	10	104,900	$533,000

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* Four product fuel oil tanks in total as a contingency to account for possible blending to different specifications.

SECTION VII

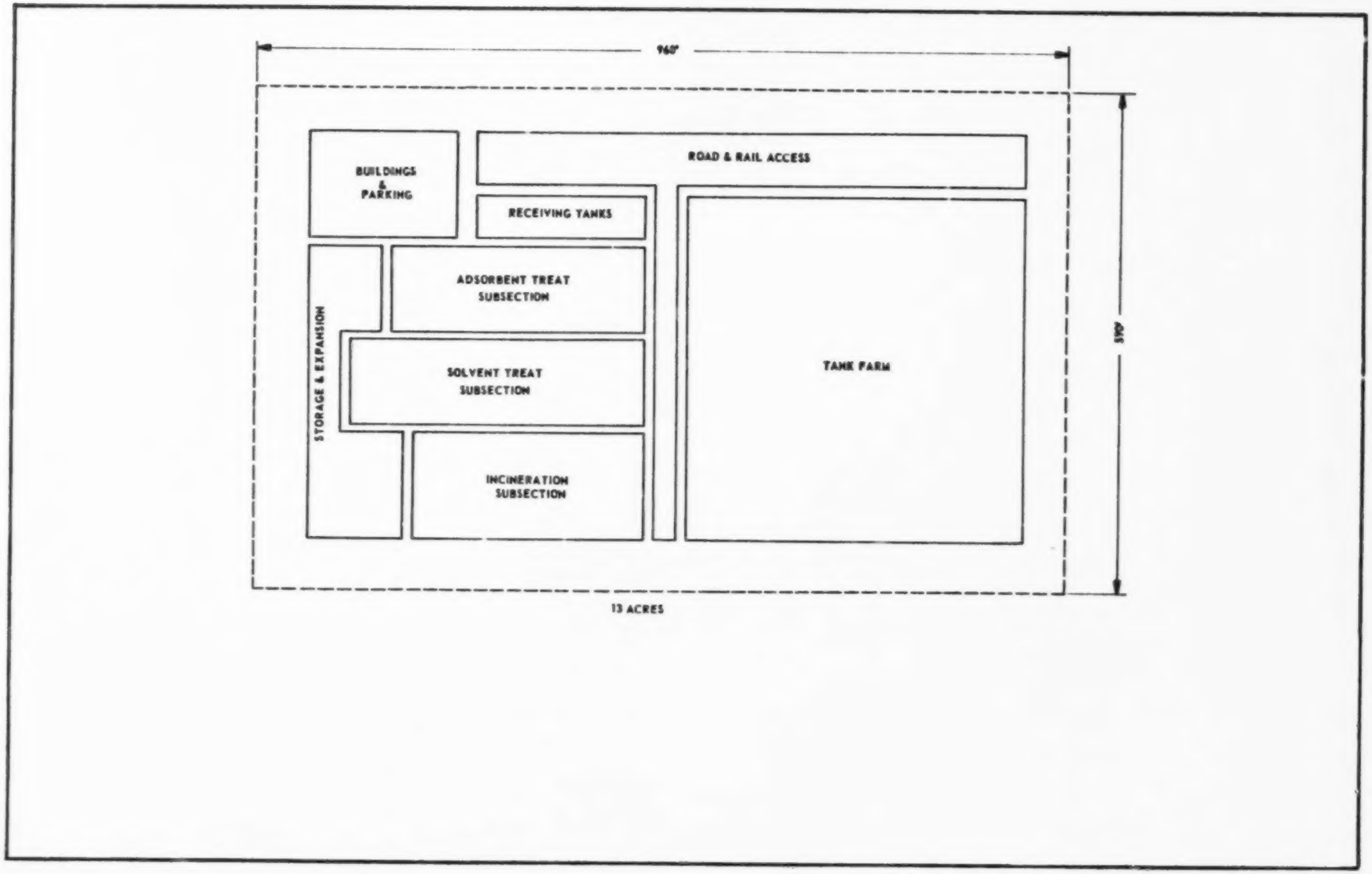
FACILITY LAND REQUIREMENTS

The previous sections on equipment and tankage design have considered site areas required on more or less an item-by-item basis. Figure 8 summarizes the results of these considerations in the form of a preliminary site plan. Land allocations for the tank farm, receiving tanks, adsorbent treatment, solvent treatment, incineration and buildings have been covered in sufficient detail in the equipment design subsections of this report.

Road and rail access to the facility will also be required; a preliminary estimate for land allocation to this function has, therefore, been included. Additional land could be required if water transport is eventually needed; access road, dock and terminal facility space would then have to be available. The land allocation for storage and expansion has been included recognizing that such space is almost always necessary in a radically new facility; it is, therefore, a suitable inclusion for preliminary design purposes. In a final estimate, this particular site allotment could, somewhat arbitrarily, be eliminated. The area indicated in the site plan as space between facility subsections and adjoining property is also a rough first estimate. A 10-foot separation between plant subsections is not at all unreasonable while the 60-foot separation with adjoining property may or may not be. Obviously, in the case of the tank farm, something like a 60-foot separation will be necessary to comply with generally recognized safety precautions. For the rest of the facility, however, 60-feet may be too generous, especially if the location is in a highly industrialized area. Actual site selection and final design may, therefore, serve to reduce this particular allocation substantially.

The above considerations may eventually prove crucial due to high land costs. Since land involves more general economic and political considerations, its cost has not been included in the capital cost estimates developed here. For example, land along Route 29/211 in Maryland can run \$500 to \$10,000 per acre, the latter typically being land with existing utility access. Industrial acreage along Route 1 can run \$2,000 to \$4,000 per acre; this is land away from residential areas and without access to utility service -- that is, water and sewerage would have to be supplied as an integral part of the process facility. More critically, waterfront property in or even near to a harbor complex (e.g., Baltimore) can easily cost \$30,000 to \$200,000 per acre; in this case, land would be the single most important cost element for the proposed facility (e.g., \$1,350,000 for a 13.5-acre site at \$100,000 per acre). With the possible price spread as indicated above, it is obvious that land costs should not be considered directly in the plant design but rather should be a factor in a more general economic analysis.

Figure 8. PRELIMINARY MES WASTE OIL RECOVERY PLANT PLOT PLAN


960'
590'
BUILDINGS & PARKING
ROAD & RAIL ACCESS
RECEIVING TANKS
ADSORBENT TREAT SUBSECTION
SOLVENT TREAT SUBSECTION
INCINERATION SUBSECTION
STORAGE & EXPANSION
TANK FARM
13 ACRES

SECTION VIII

CAPITAL COST ESTIMATES

The following pages contain capital cost estimates for both the full-scale and first-phase facilities; tank farms and process plants are considered separately since basic equipment costs and cost burdens are significantly different for the two cases. The results of these estimates ($5,700,000 and $3,060,000 capital investment for the two plants, respectively) serve as one input for a general analysis of the WORRP system.

Tank farm costs are generally for installed carbon steel tanks of the type indicated in the cost summary. Process equipment costs are generally for delivered, assembled hardware which must be set in place on foundations supplied by a general construction contractor. Basic specifications (and in some cases, capacities) are included under the equipment callouts as well as identification numbers which relate to the discussion of Section V and the process flowsheets.

Figures 9 and 10 are modifications of the basic tank farm and process flowsheets which illustrate the extent of the first-phase plant. Cost estimates for this limited facility follow the flowsheets. It must be emphasized that at an estimated capacity of 22,000 gallons per day this plant cannot be comprehensive in nature; that is, the first-phase process will be unable to treat all of Maryland's waste oils or, for that matter, even those oils which are presently being improperly disposed of. However, the unit operations included in this particular configuration do preserve the flexibility inherent in the full-scale design. In other words, every process operation and combination which is possible at full-scale can be duplicated in the first-phase plant. This includes reaction/settling, adsorbent treatment, solvent extraction, and incineration. Note that for one-third the capacity the smaller facility requires slightly more than one-half the capital investment of full-scale. Furthermore, 17 operating personnel are required for the first-phase plant as compared to 22 for full-scale. This is not a very large decrease although eventual expansion to full-scale operations was assumed in designating manpower for the first-phase plant; this is in line with the long-term goal of the proposed approach as well as the interim goal of obtaining operational experience and data before commencing State-wide, comprehensive waste oil recovery and disposal services. Additionally, by selecting elements from the full-scale design, obsolescence of equipment due to expansion to full-scale should be minimized. This contrasts to actual one-third or one-fourth scale "pilot plant" work where small-scale hardware may have no real full-scale function or value.

The capital cost estimates which follow provide not only input data for a general economic analysis but also a detailed format for consideration of and comparison to other comprehensive waste oil recovery and disposal systems.

Table 17. FULL-SCALE TANK FARM COST ESTIMATE*

Tank No.	Type	Size(gal) & Description	Number	Installed Cost**
TF 1	Receiving	16,000/horizontal,† 4 compartments	1	$ 10,800
TF 2	Receiving	19,000/horizontal, 5 compartments	1	13,200
TF 3	Receiving	23,000/horizontal, 5 compartments	1	14,800
TF 4	Receiving	12,000/horizontal, 4 compartments	1	9,300
TF 5,6	Holding	175,000/vertical, floating roof	2	52,000
TF18,24,25	Holding	75,000/vertical, fixed roof	3	57,600
TF9,10, 14,15,30	Holding	50,000/vertical, fixed roof	5	73,000
TF7,8	Holding	60,000/vertical, fixed roof	2	33,000
TF28,31	Holding	35,000/vertical, fixed roof	2	24,200
TF11,12,13, 16,17,26,29	Holding	25,000/vertical, fixed roof	7	69,300
TF19,20,21	Holding	20,000/vertical, fixed roof	3	26,100
TF27	Holding	10,000/vertical, fixed roof	1	5,900
TF22	Holding	30,000/horizontal, 3 compartments	1	14,600
TF23	Holding	40,000/horizontal, 4 compartments	1	18,300
TF40,41	Product	50,000/vertical, fixed roof	2	29,200
TF39	Product	100,000/vertical, fixed roof	1	21,300
TF35,36,37	Product	300,000/vertical, floating roof	3	92,700
TF38	Product	750,000/vertical, floating roof	1	50,200
TF33,34	Product	2,000,000/vertical, floating roof	2	192,400
TF32	Product	4,000,000/vertical, floating roof	1	147,000
		TOTALS	41	$955,000 ††

TOTAL TANK STORAGE VOLUME: 11,250,000 GALLONS

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* Includes only receiving, waste oil holding and segregation, and product storage tanks; reactor/settler tanks, miscellaneous process tanks and reagent tanks are not included.

** Estimated according to Peters and Timmerhaus and adjusted to the first quarter of 1973.

† Estimates for compartmented horizontal tanks include an additional 10% for each bulkhead plus an overall 10% increase for special fittings.

†† Total direct cost for tanks less foundations.

Table 18. FULL-SCALE TANK FARM EQUIPMENT COSTS

Tank Farm Pumps	Cost
18 Pumps (including 5 spares with an average capacity of 165 gpm at a 100-foot head for:	$ 17,300
Total Direct Pump Costs (including ±75% for field materials and +35% for direct field labor) for:	$ 40,900

Direct Equipment Costs:

Tanks * - - - - - - - - -	$1,050,000
Pumps - - - - - - - - - -	41,000
TOTAL - - -	$1,090,000

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* Includes an additional 10 percent for tank foundations.

TABLE 19

PRELIMINARY CAPITAL COST ESTIMATE FOR A FULL-SCALE MES TANK FARM

Direct Costs	$1,090,000
Indirect Costs ⓐ	270,000
Base Tank Farm Cost	$1,360,000
Site Development ⓑ	140,000
Bare Tank Farm Cost	$1,500,000
Contingency ⓒ	150,000
TOTAL ⓓ	$1,650,000

ⓐ Estimated at 25% for engineering labor, overhead, office costs, field supervision, etc.

ⓑ Estimated at 10% for preliminary purposes.

ⓒ Contingency is 10% based on 5% for site development, indirect costs and foundation estimates accuracy plus 5% for inaccuracies in basic equipment estimates.

ⓓ Does not include land costs, working capital, startup costs, owner's expenses (borrowed capital interest, legal expenses, management expenses, etc.).

Table 20. PRELIMINARY COST ESTIMATE FOR A FULL-SCALE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Reactor-Settler Tanks/Agitated, Insulated, and Heated Process Tanks of the following sizes:		
T3, 4 ----------- 20,000 gallons	2	$ 73,600
T1, 2, 7, 8 ----- 30,000 gallons	4	193,600
T5, 6 ----------- 45,000 gallons	2	132,200
Reagent Tanks/316 SS Mixing Tanks of the following sizes:		
R2, 3, 4, 6, 7 --- 275 gallons	5	$ 3,200
R5 --------------- 1,000 gallons	1	1,600
R1 --------------- 2,500 gallons	1	2,100
Process Heaters (Furnaces)/Direct-Fired Tube Heaters with adequate heating capacity to permit a 1-1/2-hour startup; the following sizes pertain:		
F1 ----------- 1,600,000 Btu/hour	1	$ 15,400
F2 ----------- 5,700,000 Btu/hour	1	25,500
F3 ----------- 2,700,000 Btu/hour	1	17,900
F4 ----------- 4,700,000 Btu/hour	1	22,600
Heat Exchangers/Fixed-Tube Sheet Heat Exchangers 1" x 16' tubes, 1-1/4 pitch, carbon steel, 150 psig rating of the following surface areas:		
I1 ----------------- 350 ft^2	1	$ 3,900
I2 ----------------- 290 ft^2	1	3,500
Air Coolers/20' tubes (CS), 150 psig, and Auto-Adjustable Fan Blades of the following sizes:		
AC2, 3, 5, 7, 8, 10 -- 100 ft^2	6	$ 13,800
AC1, 4 --------------- 210 ft^2	2	8,200
AC6 ------------------ 170 ft^2		3,400
AC9 ------------------ 535 ft^2		7,600

Table 20 (Continued). PRELIMINARY COST ESTIMATE FOR A FULL-SCALE

MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Flash Towers/single-tray suitable for vacuum and steam stripping service, 150 psig, carbon steel, with fittings and insulated and of the following sizes (diameter x height):		
FT1 -------- 4' x 18'	1	$ 3,100
FT2 -------- 4' x 22-1/2'	1	3,700
Clay Contactor/Single-Sieve Tray Splash Plate, suitable for vacuum and steam stripping service, 150 psig, carbon steel with special fittings and insulation:		
CC1 -------- 6' x 28-1/2'	1	$ 6,600
Fractionating Column/4 Bubble-Cap Trays plus spares at 100 bubble-caps per tray, including ports and nozzles, carbon steel, 150 psig, insulation and special access and fittings, 250-gallon receiver:		
FC1 -------- 2-1/2' x 20'	1	$ 3,900
Agitated Tank Reactors for solvent extraction/carbon steel, 150 psig, insulated including access ports and fittings, cooling capability, external and internal:		
AT1, 2 ----- 7,100 gallons	2	$ 66,200
Solvent Extraction Holding Tanks/volatiles service, 150 psig, including special fittings, control ports, and vents, CS, of the following sizes:		
T10 -------- 15,500 gallons	1	$ 7,000
T11 -------- 22,000 gallons	1	9,800
T9 --------- 9,500 gallons	1	6,500
T12 A & B -- 10,000 & 20,000 gallons	2	9,100

Table 20 (Continued). PRELIMINARY COST ESTIMATE FOR A FULL-SCALE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Clay Addition Tank/Agitated CS Tank with vents, variable speed control, connections, cooling circuit, 10-minute mixing time:		
CT1 -------- 30-gallon capacity	1	$ 2,500
Clay Belt Feeder and Feed Hopper/Vibrating Hopper, variable speed drive, CS and Neoprene, grizzly screen:		
BC1/SF1 ---- 550 pounds/hour capacity	1	$ 4,000
Rotary Precoat Filters/design of 7 gallons per hour per ft^2, CS, including vents, precoat system, vacuum pumps, internal piping and controls, 260 ft^2 of filter area:		
RF1, 2 ----- (about) 8' x 12' in size	2	$ 67,800
Spent Clay Conveyors/basic belt construction:		
BC2, 3, 4 -- Sized for pertinent flow stream	3	$ 2,400
Clay Incineration Kiln/CS, firebrick construction, grate area of 311 ft^2, 10 feet in diameter, includes vents, ports, controls, and auxiliary equipment, maximum instantaneous capacity of:		
K1 --------- 750 pounds/hour	1	$ 45,000
Routine Incinerator/Steam Injection, CS and firebrick construction, including dust collector subsystem, capacity of:		
IN1 -------- 9×10^8 Btu/day	1	$ 73,500

Table 20 (Continued). PRELIMINARY COST ESTIMATE FOR A FULL-SCALE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Controlled Incinerator/as for I1 but without dust collector subsystem, capacity of: IN2 ------ 16 x 10^8 Btu/day	1	$ 70,000
Particulates Venturi Scrubber/Lined CS for acid service at 200°F: VS1 ------ 17,100 SCFM throughput	1	$ 52,500
Acid Gas Venturi Scrubber/as for VS1 but: VS2 ------ 150°F caustic service	1	$ 45,000
Particulates Clarifier/CS Tank, capacity of: CL1 ------ 33 gpm	1	$ 7,900
Acid Salts Clarifier/CS Tank, capacity of: CL2 ------ 51 gpm	1	$ 7,900
Rotary Filter, 304 SS, for acid salts/ complete system including ports, pumps, valves, and fittings, 100 ft^2, 5-1/2 tons of solids filtered per day: RF3	1	$ 34,000
Particulate Sludge Storage Tank/epoxy-lined CS, covered, with ports and fittings, capacity of: PS1 ------ 39,000 gallons	1	$ 7,900
Gypsum Storage Tank/epoxy-lined CS, covered, with ports and fittings, capacity of: PS2 ------ 22,000 gallons	1	$ 4,600

Table 20 (Continued). PRELIMINARY COST ESTIMATE FOR A FULL-SCALE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Slaker and Slaker Feed Hopper/CS, with fittings, vents, and control ports, 2700-ft^3 hopper, 9 TPD Slaker:		
SL1	1	\$ 12,200
Incinerator Subsection Pumps	9	\$ 6,100
Metering Pumps (Process)	15	\$ 4,500
Process Pumps	21	\$ 14,300
TOTALS	102	\$1,110,000

Table 21. PRELIMINARY CAPITAL COST ESTIMATE FOR A FULL-SCALE MES WASTE OIL RECOVERY PLANT*

Basic Equipment Costs	$ 1,110,000
Field Materials (75%)[a]	820,000
Direct Material	$ 1,930,000
Direct Field Labor (35%)	650,000
Direct Costs	$ 2,580,000
Indirect Costs (43%)[b]	1,110,000
Bare Module Cost[c]	$ 3,690,000
Plant Buildings[d]	170,000
Base Plant Cost	$ 3,860,000
Site Development[e]	190,000
Estimated Total Plant Cost	$ 4,050,000
Estimated Working Capital	$ 160,000

---

* Total costs estimated from "Rapid Calculation Charts", Chemical Engineering, Jan. 13, 1969 for carbon steel. Does not include land costs.

[a] Secondary cost element including piping, instrumentation, foundations and other concrete work, local steel, electrical materials, paint, etc.

[b] Secondary cost element including construction overhead (field supervision, temporary field facilities, small tools, etc.) and engineering and contractor fee (direct engineering labor, overhead office costs, etc.) and interest during construction, owners' costs & 1 month's startup.

[c] This cost does not include site development, pilings, buildings, major storage or other offsite facilities.

[d] Laboratory, office, warehouse and shop space, fully equipped.

[e] Estimated at 5 percent for this process plant module.

Table 22. PLANT CAPITAL CONTINGENCY ESTIMATE

Based on the methodology used to arrive at the estimated plant cost, various allowances for inaccuracies should be made. These are estimated as follows:

Allowance for Unlisted or Additional Items -- 8%

Allowance for Equipment Cost Estimates ------ 12%

TOTAL CONTINGENCY -- 20%

Using these values, the monetary contingency is $810,000, which increases the potential total plant cost to $4,860,000.

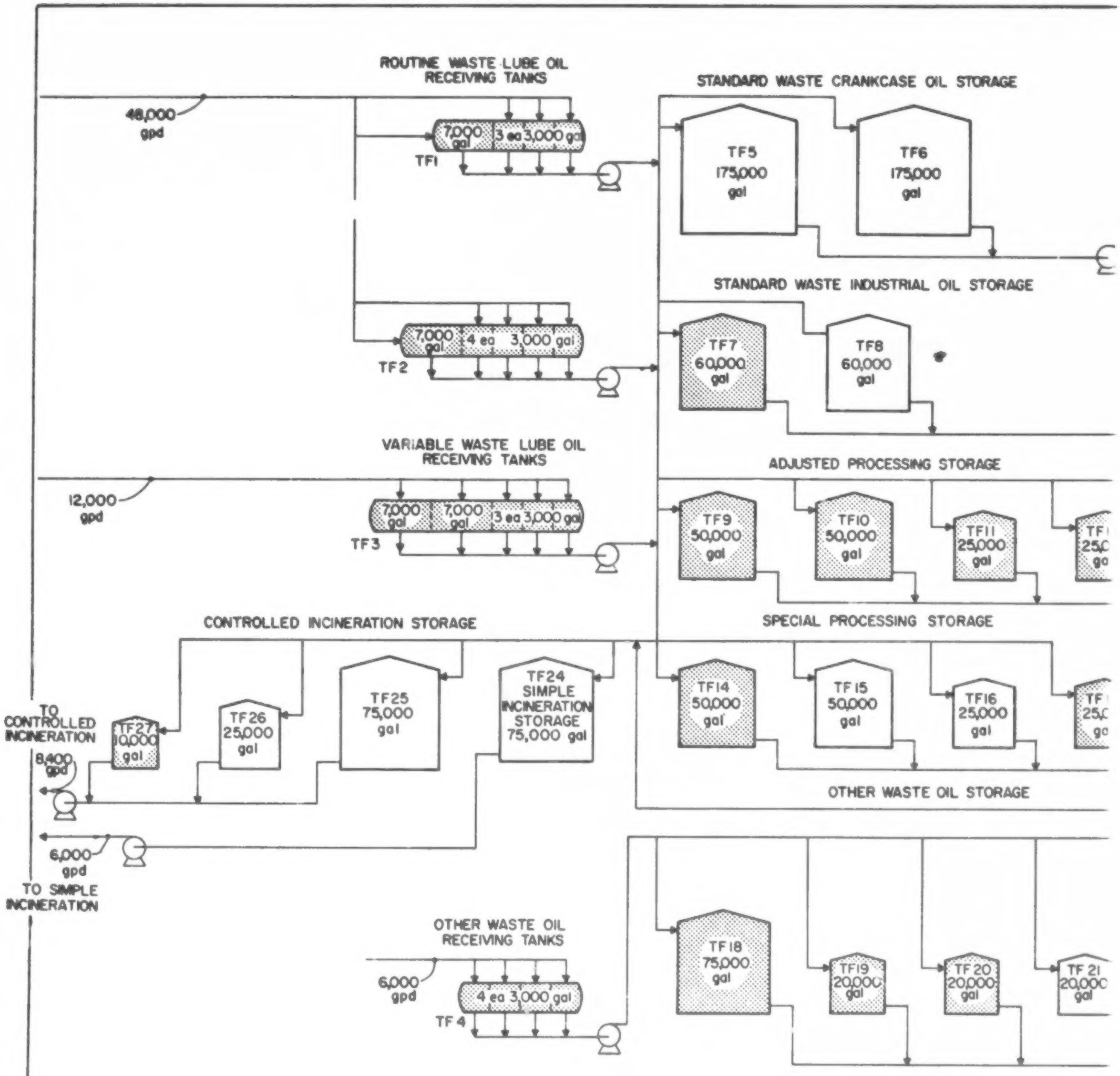
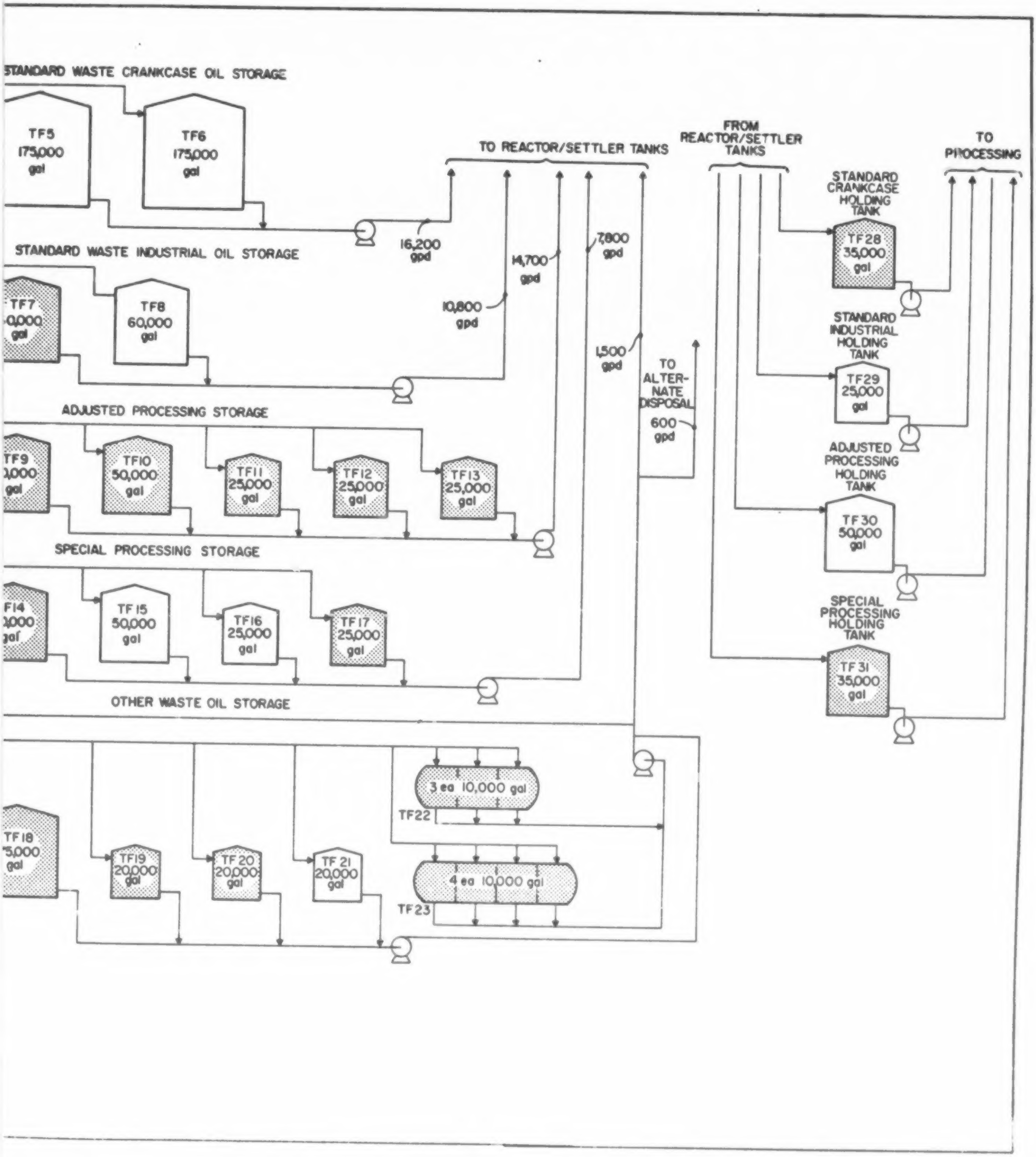

ROUTINE WASTE LUBE OIL RECEIVING TANKS
48,000 gpd
7,000 gal
3 ea 3,000 gal
TF1
STANDARD WASTE CRANKCASE OIL STORAGE
TF5 175,000 gal
TF6 175,000 gal
7,000 gal
4 ea 3,000 gal
TF2
STANDARD WASTE INDUSTRIAL OIL STORAGE
TF7 60,000 gal
TF8 60,000 gal
VARIABLE WASTE LUBE OIL RECEIVING TANKS
12,000 gpd
7,000 gal
7,000 gal
3 ea 3,000 gal
TF3
ADJUSTED PROCESSING STORAGE
TF9 50,000 gal
TF10 50,000 gal
TF11 25,000 gal
CONTROLLED INCINERATION STORAGE
SPECIAL PROCESSING STORAGE
TO CONTROLLED INCINERATION
8,400 gpd
TF27 10,000 gal
TF26 25,000 gal
TF25 75,000 gal
TF24 SIMPLE INCINERATION STORAGE 75,000 gal
TF14 50,000 gal
TF15 50,000 gal
TF16 25,000 gal
OTHER WASTE OIL STORAGE
6,000 gpd
TO SIMPLE INCINERATION
OTHER WASTE OIL RECEIVING TANKS
6,000 gpd
4 ea 3,000 gal
TF 4
TF18 75,000 gal
TF19 20,000 gal
TF 20 20,000 gal
TF 21 20,000 gal

Figure 9. PRELIMINARY MES WASTE OIL RECEIVING AND FEEDSTOCK TANKAGE -- FIRST-PHASE ELEMENTS


STANDARD WASTE CRANKCASE OIL STORAGE
TF5 175,000 gal
TF6 175,000 gal
TO REACTOR/SETTLER TANKS
FROM REACTOR/SETTLER TANKS
TO PROCESSING
16,200 gpd
14,700 gpd
7,800 gpd
10,800 gpd
1,500 gpd
600 gpd
STANDARD WASTE INDUSTRIAL OIL STORAGE
TF7 0,000 gal
TF8 60,000 gal
TO ALTERNATE DISPOSAL
STANDARD CRANKCASE HOLDING TANK
TF28 35,000 gal
STANDARD INDUSTRIAL HOLDING TANK
TF29 25,000 gal
ADJUSTED PROCESSING STORAGE
TF9 0,000 gal
TF10 50,000 gal
TF11 25,000 gal
TF12 25,000 gal
TF13 25,000 gal
ADJUSTED PROCESSING HOLDING TANK
TF30 50,000 gal
SPECIAL PROCESSING STORAGE
F14 0,000 gal
TF15 50,000 gal
TF16 25,000 gal
TF17 25,000 gal
SPECIAL PROCESSING HOLDING TANK
TF31 35,000 gal
OTHER WASTE OIL STORAGE
3 ea 10,000 gal
TF22
4 ea 10,000 gal
TF23
TF18 5,000 gal
TF19 20,000 gal
TF 20 20,000 gal
TF 21 20,000 gal

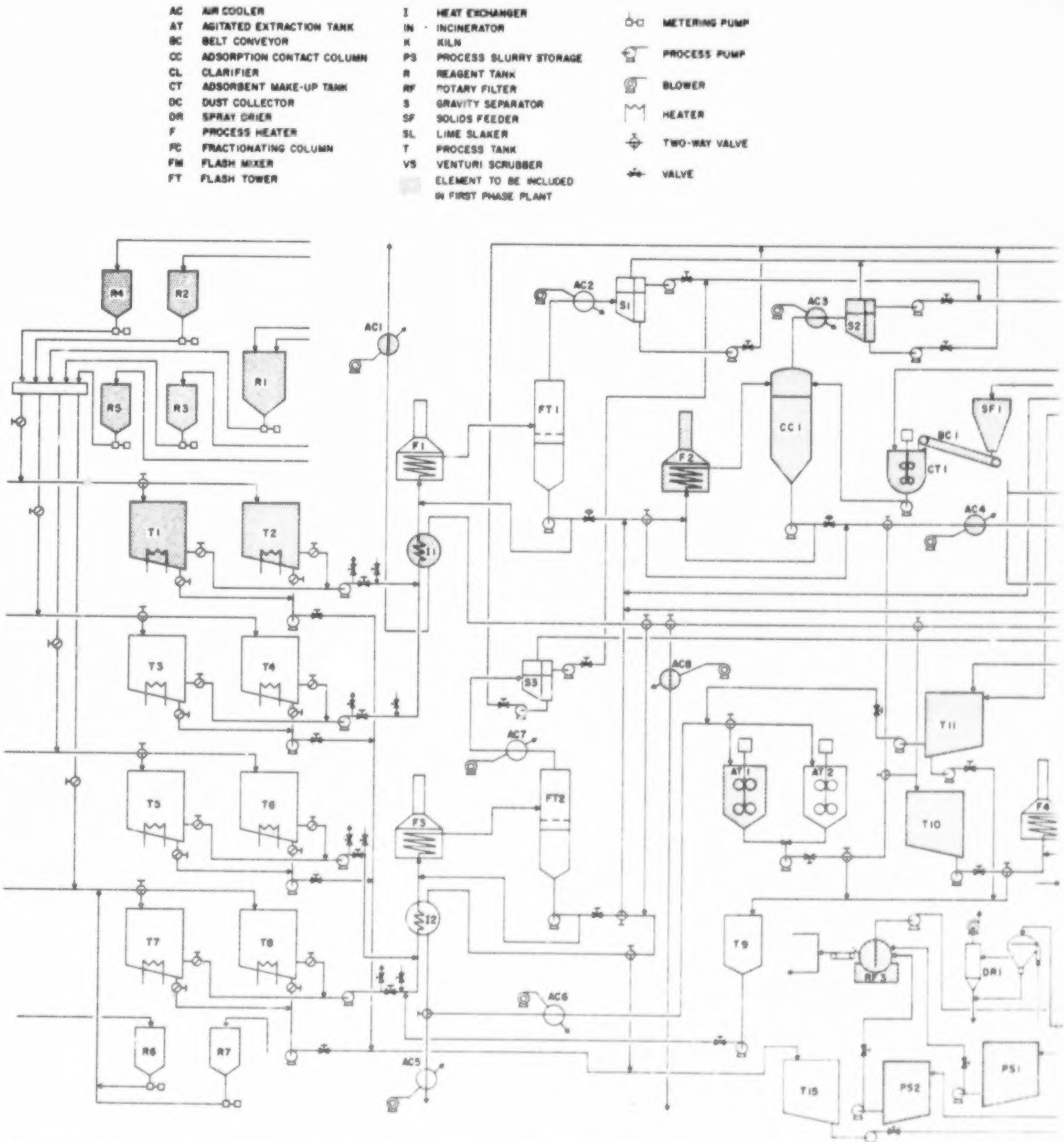

AC AIR COOLER
AT AGITATED EXTRACTION TANK
BC BELT CONVEYOR
CC ADSORPTION CONTACT COLUMN
CL CLARIFIER
CT ADSORBENT MAKE-UP TANK
DC DUST COLLECTOR
DR SPRAY DRIER
F PROCESS HEATER
FC FRACTIONATING COLUMN
FM FLASH MIXER
FT FLASH TOWER
I HEAT EXCHANGER
IN INCINERATOR
K KILN
PS PROCESS SLURRY STORAGE
R REAGENT TANK
RF ROTARY FILTER
S GRAVITY SEPARATOR
SF SOLIDS FEEDER
SL LIME SLAKER
T PROCESS TANK
VS VENTURI SCRUBBER
ELEMENT TO BE INCLUDED IN FIRST PHASE PLANT
METERING PUMP
PROCESS PUMP
BLOWER
HEATER
TWO-WAY VALVE
VALVE
R4
R2
R1
R5
R3
AC1
F1
I1
FT1
AC2
S1
AC3
S2
CC1
F2
BC1
SF1
CT1
AC4
T1
T2
T3
T4
S3
AC8
T5
T6
AC7
FT2
F3
T11
AT1
AT2
T10
F4
T7
T8
I2
T9
RF3
DR1
AC6
R6
R7
AC5
T15
PS2
PS1

Figure 10. PRELIMINARY MES WASTE OIL RECOVERY SYSTEM -- FLOW SHEET - FIRST-PHASE ELEMENTS

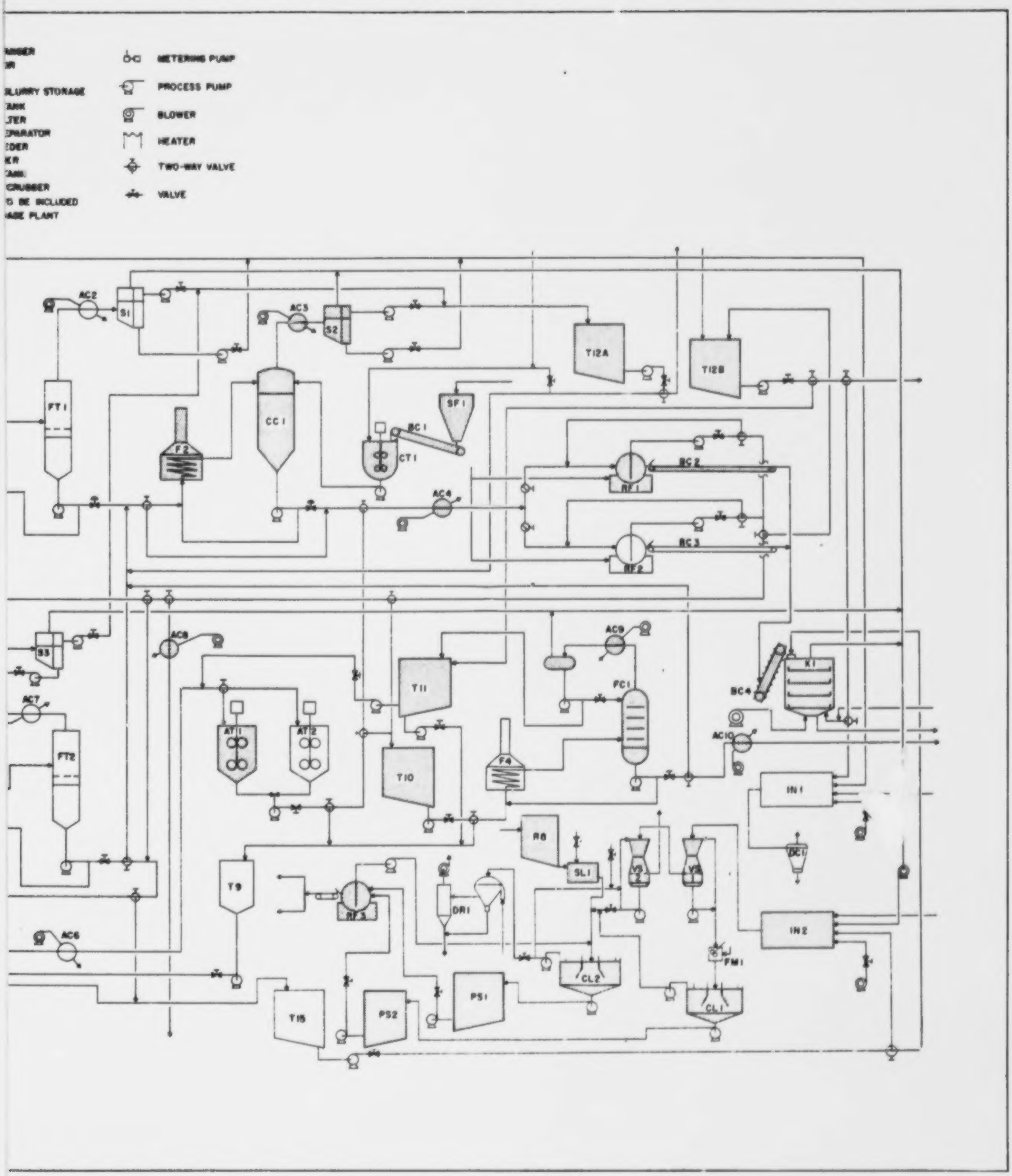

ANGER
OR
SLURRY STORAGE
TANK
LTER
EPARATOR
EDER
KER
TANK
CRUBBER
O BE INCLUDED
AGE PLANT
METERING PUMP
PROCESS PUMP
BLOWER
HEATER
TWO-WAY VALVE
VALVE
AC2
S1
AC3
S2
T12A
T12B
FT1
F2
CC1
SF1
BC1
CT1
AC4
RF1
BC2
RF2
BC3
S3
AC8
AC9
T11
FC1
BC4
K1
AC7
AT1
AT2
FT2
T10
F4
AC10
IN1
R8
SL1
VS 2
VS
DC1
T9
RF3
DR1
IN2
AC6
FM1
CL2
CL1
T15
PS2
PS1

Table 23. FIRST-PHASE TANK FARM COST ESTIMATE*

Tank No.	Type	Size(gal) & Description	Number	Installed Cost**
TF 1	Receiving	16,000/horizontal,† 4 compartments	1	$ 10,800
TF 2	Receiving	19,000/horizontal, 5 compartments	1	13,200
TF 3	Receiving	24,000/horizontal, 5 compartments	1	14,800
TF 4	Receiving	12,000/horizontal, 4 compartments	1	9,300
TF 18	Holding	75,000/vertical, fixed roof	1	19,200
TF 9,10, 14	Holding	50,000/vertical, fixed roof	3	43,800
TF 7	Holding	60,000/vertical, fixed roof	1	16,500
TF 28,31	Holding	35,000/vertical, fixed roof	2	24,200
TF 11,12, 13,16	Holding	25,000/vertical, fixed roof	4	39,600
TF 19,20	Holding	20,000/vertical, fixed roof	2	17,400
TF 27	Holding	10,000/vertical, fixed roof	1	5,900
TF 22	Holding	30,000/horizontal, 3 compartments	1	14,600
TF 23	Holding	40,000/horizontal, 4 compartments	1	18,300
TF 40	Product	50,000/vertical, fixed roof	1	14,600
TF 39	Product	100,000/vertical, fixed roof	1	21,300
TF 34;35	Product	300,000/vertical, floating roof	2	61,800
TF 38	Product	750,000/vertical, floating roof	1	50,200
TF 33	Product	2,000,000/vertical, floating roof	1	96,200
	TOTALS ------------------------------------			$491,700††

TOTAL TANK STORAGE VOLUME: 4,145,000 GALLONS

---

* Includes only receiving, waste oil holding and segregation, and product storage tanks; reactor/settler tanks, miscellaneous process tanks and reagent tanks are not included.

** Estimated according to Peters and Timmerhaus and adjusted to the first quarter of 1973.

† Estimates for compartmented horizontal tanks include an additional 10% for each bulkhead plus an overall 10% increase for special fittings.

†† Total direct cost for tanks less foundations.

Table 24. TANK FARM EQUIPMENT COSTS

Tank Farm Pumps		Costs
13 pumps (including 4 spares with an average capacity of 165 gpm at a 100 foot head) for:		$ 12,500
Total Direct Pump Costs (inc. +75% for field materials & +35% for direct field labor) for:		$ 24,500
Direct Equipment Costs:		
	Tanks*	$541,000
	Pumps	24,000
	TOTAL	$565,000

---

* Includes an additional 10% for tank foundations.

Table 25. PRELIMINARY CAPITAL COST ESTIMATE FOR A FIRST-PHASE MES TANK FARM

Direct Costs	$ 565,000
Indirect Costs ⓐ	141,000
Base Tank Farm Cost	$ 706,000
Site Development ⓑ	71,000
Bare Tank Farm Cost	$ 777,000
Contingency ⓒ	78,000
TOTAL ⓓ	$ 860,000

ⓐ Estimated at 25% for engineering labor, overhead, office costs, field supervision, etc.

ⓑ Estimated at 10% for preliminary purposes.

ⓒ Contingency is 10% based on 5% for site development, indirect costs and foundation estimates accuracy plus 5% for inaccuracies in basic equipment estimates.

ⓓ Does not include land costs, working capital, startup costs, owner's expenses (borrowed capital interest, legal expenses, management expenses, etc.)

Table 26. PRELIMINARY COST ESTIMATE FOR A FIRST-PHASE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Reactor-Settler Tanks/Agitated, Insulated, and Heated Process Tanks of the following sizes:		
T1, 2 ----- 30,000 gallons	2	$ 96,800
Reagent Tanks/316SS Mixing Tanks of the following sizes:		
R1 -------- 2,500 gallons	1	$ 2,100
R2, 3, 4 -- 275 gallons	3	1,900
R5 -------- 1,000 gallons	1	1,600
Process Heater (Furnace)/Direct-Fired Tube Heater with adequate heating capacity to permit a 1-1/2-hour startup of the following size pertains:		
F2 -------- 5,700,000 Btu/hour	1	$ 25,500
Heat Exchanger/Fixed-Tube Sheet Heat Exchanger, 1" x 16' tubes, 1-1/4 pitch, carbon steel, 150 psig rating of the following surface area:		
I1 -------- 350 ft^2	1	$ 3,900
Air Coolers/20' Tubes (CS), 150 psig, and Auto-Adjustable Fan Blades of the following sizes:		
AC3, 8, 10 -- 100 ft^2	3	$ 6,900
AC1, 4 ------ 210 ft^2	2	8,200
AC9 --------- 535 ft^2	1	7,600
Clay Contactor/Single-Sieve Tray Splash Plate, suitable for vacuum and steam stripping service, 150 psig, carbon steel with special fittings and insulation:		
CC1 --------- 6' x 28-1/2'	1	$ 6,600

Table 26 (Continued). PRELIMINARY COST ESTIMATE FOR A

FIRST-PHASE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Fractionating Column/4 Bubble-Cap Trays plus spares at 100 bubble caps per tray; including ports and nozzles, carbon steel, 150 psig, insulation and special access and fittings, 250-gallon receiver:		
FC1 -------- 2-1/2' x 20'	1	$ 3,900
Agitated Tank Reactor for solvent extraction/ carbon steel, 150 psig, insulated including access ports and fittings, cooling capability, external and internal:		
AT1 -------- 7,100 gallons	1	$ 33,100
Solvent Extraction Holding Tanks/volatiles service, 150 psig, including special fittings, control ports and vents, CS, of the following sizes:		
T10 -------- 15,500 gallons	1	$ 7,000
T11 -------- 22,000 gallons	1	9,800
T12 A & B -- 10,000 & 20,000 gallons	2	9,100
Clay Addition Tank/ Agitated CS Tank, with vents, variable speed control, connections, cooling circuit, 10-minute mixing time:		
CT1 -------- 30-gallon capacity	1	$ 2,500
Clay Belt Feeder and Feed Hopper/Vibrating Hopper, variable speed drive, CS and Neoprene, Grizzly Screen:		
BC1/SF1 ---- 550 pounds/hour capacity	1	$ 4,000

Table 26 (Continued). PRELIMINARY COST ESTIMATE FOR A FIRST-PHASE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Rotary Precoat Filters/design of 7 gallons/hour/ft^2, CS, including vents, precoat system, vacuum pumps, internal piping and controls, 260 ft^2 of filter area:		
RF1 ----- 8' x 12' in size	1	$ 33,900
Spent Clay Conveyors/basic belt construction:		
BC2, 3 -- sized for pertinent flow stream	1	$ 1,200
Clay Incineration Kiln/CS, firebrick construction, grate area of 311 ft^2, 10-foot diameter, includes vents, ports, controls and auxiliary equipment, maximum instantaneous capacity of:		
K1 ------ 750 pounds/hour	1	$ 45,000
Controlled Incinerator/as for I1 but without dust collector subsystem; capacity of:		
IN2 ----- 16 x 10^8 Btu/day	1	$ 70,000
Particulates Venturi Scrubber/lined CS for acid service at 200°F:		
VS1 ----- 17,100 SCFM throughput	1	$ 52,500
Acid Gas Venturi Scrubber/as for VS1 but:		
VS2 ----- 150°F caustic service	1	$ 45,000
Particulates Clarifier/CS Tank, capacity of:		
CL1 ----- 33 gpm	1	$ 7,900

Table 26 (Continued). PRELIMINARY COST ESTIMATE FOR A FIRST-PHASE MES WASTE OIL RECOVERY PROCESS PLANT

- Basic Equipment Costs -

Item/Description	No.	Total Cost
Acid Salts Clarifier/CS Tank, capacity of: CL2 ----- 51 gpm	1	$ 7,900
Rotary Filter, 304 SS, for Acid Salts/complete system including ports, pumps, valves, and fittings, 100 ft^2, 5-1/2 tons solids filtered per day: RF3	1	$ 34,000
Particulate Sludge Storage Tank/epoxy-lined CS, covered, with ports and fittings, capacity of: PS1 ----- 39,000 gallons	1	$ 7,900
Gypsum Storage Tank/epoxy-lined CS, covered with ports and fittings, capacity of: PS2 ----- 22,000 gallons	1	$ 4,600
Slaker and Slaker Feed Hopper/CS, with fittings, vents, and control ports, 2700-ft^3 hopper, 9TPD slaker: SL1	1	$ 12,200
Incinerator Subsection Pumps	9	$ 6,100
Metering Pumps (Process)	9	$ 2,700
Process Pumps	12	$ 8,200
TOTALS -----	67	----- $570,000

Table 27. PRELIMINARY CAPITAL COST ESTIMATE FOR A FIRST-PHASE MES WASTE OIL RECOVERY PLANT*

Basic Equipment Costs	$ 570,000
Field Materials (75%)[a]	428,000
Direct Material	$ 998,000
Direct Field Labor (35%)	349,000
Direct Costs	$1,347,000
Indirect Costs (43%)[b]	580,000
Bare Module Cost[c]	$1,927,000
Plant Buildings[d]	170,000
Base Plant Cost	$2,097,000
Site Development[e]	105,000
Estimated Total Plant Cost	$2,200,000
Estimated Working Capital	$ 125,000

---

* Total costs estimated from "Rapid Calculation Charts", Chemical Engineering, Jan. 13, 1969 for carbon steel. Does not include land costs.

[a] Secondary cost element including piping, instrumentation, foundations and other concrete work, local steel, electrical materials, paint, etc.

[b] Secondary cost element including construction overhead (field supervision, temporary field facilities, small tools, etc.) and engineering and contractor fee (direct engineering labor, overhead office costs, etc.) and interest during construction, owner's costs & 1 month's startup.

[c] This cost does not include site development, pilings, buildings, major storage or other offsite facilities.

[d] Laboratory, office, warehouse and shop space, fully equipped.

[e] Estimated at 5 percent for this process plant module.

Table 28. FIRST-PHASE PLANT CAPITAL CONTINGENCY ESTIMATE

Based on the methodology used to arrive at the estimated plant cost, various allowances for inaccuracies should be made. These are estimated as follows:

Allowance for Calculation Chart Accuracy	4%
Allowance for Unlisted or Additional Items	6%
Allowance for Equipment Cost Estimates	10%
TOTAL CONTINGENCY	20%

Using these values, the monetary contingency is $440,000, which increases the potential total plant cost to $2,640,000.

SECTION IX

OPERATING AND MAINTENANCE ESTIMATES

The following pages contain tabulated summaries related to the operation and maintenance of both the full-scale and first-phase facilities as well as the oils produced by the same. Cost estimates refer to the process plant as an independent entity and are for the purposes of preliminary design summary only. Complete economic estimates, including the process plant are contained in the main report for the project which has been submitted under separate cover.

Plant Staffing

Tables 29 and 30 give the plant personnel necessary for 24-hour operation of the full-scale and first-phase facilities, respectively.

The following discussion is directed at the full-scale facility. Besides a plant manager, two chemists are included to provide laboratory services; such services would include preliminary waste oil characterization, process testing and product control as well as limited process development work. The plant engineer would be in charge of all handling and processing facilities on a day-to-day basis. Fourteen plant operators, ranging from chiefs to assistants, would be required to run the actual process operations; this works out to slightly more than 3 men per shift. The yardman will be in charge of the plant's waste oil receiving facility; he will probably require occasional assistance from other plant personnel. The plant clerk will be responsible for the basic bookkeeping tasks associated with plant operations: recording waste oil deliveries, accounting functions, timekeeping, monitoring customer charges, and control over oil products. Two maintenance men have been included to provide in-house maintenance services on a continuous basis. The total for the full-scale plant is 22 men which includes approximately 8 percent excess labor to account for vacation and sick leave.

The first-phase facility requires only 17 people. The decreased number is due to use of only 10 operators and a single maintenance man. Again, 24-hour operation has been assumed for this level of staffing.

Preliminary Operating Cost and Net Profit Estimates

Tables 31 and 32 contain operating and maintenance cost estimates for the full-scale and first-phase facilities, respectively. For the sake of completeness, initial estimates of product and service revenues, equipment and plant lease (a factor similar to amortized investment), and insurance charges are included to allow an estimate of net profit before taxes. Note that the indicated plant lease is equivalent to about a 12 percent interest rate on investment capital. Again, these calculations do not include allowances for collection costs, overall system management, extensive research and development, etc. Keeping these factors in mind, the full-scale facility will do a little better than breaking even while the first-phase facility will incur a moderate deficit.

TABLE 29

FULL SCALE PLANT STAFFING*

	Title	Shift & Day Assignment	No.
1)	Plant Manager	(first shift, Mon.-Fri.)	1
2)	Chief Chemist	(first shift, Mon.-Fri.)	1
3)	Assistant Chemist	(first shift, Mon.-Fri.)	1
4)	Plant Engineer	(first shift, Mon.-Fri.)	1
5)	Chief Operator	(first shift, Fri.-Tues.) and 2nd & 3rd shifts, Mon.-Fri.)	3
6)	Assistant Chief	(three shifts, Wed.-Sun.)	3
7)	Plant Operator	(three shifts, Wed.-Sun.)	3
8)	Assistant Operator	(three shifts, Mon.-Fri. and 2nd & 3rd shifts, Fri.-Tues.)	5
9)	Yardman	(first shift, Mon.-Fri.)	1
10)	Clerk	(first shift, Mon.-Fri.)	1
11)	Maintenance	(first shift, Mon.-Fri.)	2
			22

---

* Includes about 8 percent excess labor to account for swing shifts due to vacation and sick leaves.

Table 30. FIRST-PHASE PLANT STAFFING*

Title	Shift and Day Assignment	No.
1. Plant Manager	1st shift -- Mon. thru Fri.	1
2. Chemist	1st shift -- Mon. thru Fri.	1
3. Assistant Chemist	1st shift -- Mon. thru Fri.	1
4. Plant Engineer	1st shift -- Mon. thru Fri.	1
5. Chief Operator	1st shift -- Fri. thru Tues. & 2nd and 3rd shifts -- Mon. thru Fri.	3
6. Assistant Chief	Three shifts -- Wed. thru Sun.	3
7. Plant Operator	1st shift -- Mon. thru Fri. & 2nd and 3rd shifts -- Fri. thru Tues.	3
8. Assistant Operator	1st shift -- Mon. thru Fri.	1
9. Yardman	1st shift -- Mon. thru Fri.	1
10. Clerk	1st shift -- Mon. thru Fri.	1
11. Maintenance	1st shift -- Mon. thru Fri.	1
	Total ------	17

---

* Includes about 8 percent excess labor to account for swing shifts due to vacation and sick leaves.

Table 31. PRELIMINARY DESIGN OPERATING COST AND NET PROFIT ESTIMATE FOR A FULL-SCALE WASTE OIL PROCESSING FACILITY

- Fuel Oil Option -

Estimated Capital Cost: $ 5,700,000

66,000 GPD total capacity

330 stream days/year - - - - - - transport costs recovered by truckers

- - - - -

Yield - - - - - 330 x 66,000 x 0.62 = 13.5 x 10^6 gallons

Lube Oil - - - - - - 500,000 gal/yr

Fuel Oil - - - - - - 13 x 10^6 + 25% = 16.2 x 10^6 gal/yr

Disposal Oils - - - - 14,400 GPD x 330 = 4.8 x 10^6 gal/yr

Fuel Price - - - - - - 12.2¢/gallon

Lube Oils - - - - - - 20¢/gallon

Disposal - - - - - - - 10¢/gallon

Revenue - - - - -

Fuel Oils - - 16.2 x 10^6 x $0.122 - - $1,978,000

Lube Oils - - 5 x 10^5 x $0.20 - - 100,000

Disposal - - 4.8 x 10^6 x $0.10 - - 480,000

TOTAL - - $2,558,000/year

Costs - - - - -

Equipment and Plant Lease : $168/year/$1000 of capital investments*

Base of $5.7 x 10^6 implies : $958,000/year fixed charges

---

* Private communication for 10-Year Lease.

Table 31 (Continued). PRELIMINARY DESIGN OPERATING COST AND NET PROFIT ESTIMATE FOR A FULL-SCALE WASTE OIL PROCESSING FACILITY

Labor

22 people @ $14,000/year	$308,000/year
DLO @ 30%	92,000
G&A @ 15%	46,000
TOTAL	$446,000/year

Operation

Chemicals:

Lime	5000 ppd	@ $0.0125	$ 62.5	
NaOH	4000 ppd	@ 0.04	160.0	
Additives	75 ppd	@ 0.30	22.5	
Solvents	225 gpd	@ 0.20	45.0	
Adsorbent	6600 ppd	@ 0.05	330.0	
			$620/day x 330 =	$204,000

Cutter Stock: 3.2 x 10^6 gpy x $0.122	390,000
Lube Oil Cutter Stock: 125,000 gpy @ 20¢	25,000
Process Fuel: 12.2¢/gal. and 500 gpd, $61/day x 330 days=	20,000
Power: 330 days x 24 hr/day x 300 kw x $.02/kw-hr	48,000
SUBTOTAL	$687,000
Office G&A @ 10%	69,000
TOTAL	$756,000

Maintenance - - - - - @ 2% of Capital - - - - - - - - - - - - - - $114,000

Summary:

Labor	$ 446,000
Operation	756,000
Maintenance	114,000
O&M Subtotal	$1,316,000
Lease	958,000
Insurance @ 1%	57,000
Total	$2,331,000
Sales Revenue	$2,558,000
Net Profit Before Taxes	$ 227,000/year

Table 32. PRELIMINARY DESIGN OPERATING COST AND NET PROFIT ESTIMATE FOR A FIRST- PHASE WASTE OIL PROCESSING FACILITY

- Fuel Oil Option -

Estimated Capital Cost: $ 2,980,000

22,000 GPD processing capacity plus 8,400 GPD of non-recoverables incineration

330 stream-days/year - - - - - - transport costs recovered by truckers

- - - - -

Yield - - - - - 330 x 22,000 x 0.78 = 5.7 x 10^6 gallons

Fuel Oil - - - - - - - - 5.7 x 10^6 + 25% = 7.12 x 10^6 gal/yr

Disposal Oils - - - - - 8,400 GPD x 330 = 2.77 x 10^6 gal/yr

Fuel Price - - - - - - - - - - 12.2¢/gallon

Disposal - - - - - - - - - - - 10¢/gallon

Revenue - - - - -

Fuel Oils - - - - 7.12 x 10^6 x $0.122 = $ 869,000

Disposal - - - - 2.77 x 10^6 x $0.10 = 277,000

TOTAL = $1,146,000/year

Costs - - - - -

Equipment and Plant Lease: $168/year/$1000 of capital investments*

Base of $2.98 x 10^6 implies: $500,000/year fixed charges.

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* Private Communication for 10-Year Lease.

Table 32 (Continued). PRELIMINARY DESIGN OPERATING COST AND NET PROFIT ESTIMATE FOR A FIRST-PHASE WASTE OIL PROCESSING FACILITY

Labor	
17 people @ $14,000/year	$238,000/year
DLO @ 30%	71,000
G&A @ 15%	36,000
TOTAL	$345,000/year
Operation	
Chemicals: $264/day x 330 days	$ 87,000
Cutter Stock: 1.42 x 10^6 gpy x $0.122	173,000
Process Fuel	9,000
Power	20,000
SUBTOTAL	$289,000
Office G&A @ 10%	29,000
TOTAL	$318,000
Maintenance @ 2% of Capital	$ 60,000
Summary:	
Labor	$ 345,000
Operation	318,000
Maintenance	60,000
O&M Subtotal	$ 723,000
Lease	500,000
Insurance @ 1%	30,000
Total	$1,253,000
Sales Revenue	$1,146,000
Net Profits Before Taxes	$ 107,000/year DEFICIT

Product Oils

Due to the extensive flexibility of the proposed facility for both processing different waste oils and producing a wide range of products, product selection can, in many ways, be relegated to a problem of marketing and sales. These factors have, in fact, been of primary importance in designating fuel oil as the major product for the initial system configuration.

Table 33 summarizes the various full-scale product flows from the basic process variations as a function of waste oil type. Yields are included for the sake of comparison between process and overall plant efficiencies. The plant yield is 62 percent. The 38 percent waste oil loss includes oily wastes which go directly to ultimate disposal; the other total yield percentages also include such an allowance. The 40,700 gallons of (predominantly fuel oil) product per stream-day is a net value; that is, it includes adjustment for oil which must be added to the primary process stream during treatment (e.g., carrier liquid and treatment additives).

The basic products which may be produced by the plant include fuels, lubricants and solvents. The fuels are primarily heating oil grades such as No. 4 and No. 5. Additionally, No. 6 heating oil can be produced in quantity depending on the viscosity of the waste oil feedstocks and the use of appropriate cutter stock. Also, lubricants including hydraulic oils and motor oils can be produced depending on the composition and amounts of waste oil feedstock and marketing factors; treatment to finished lube product will, however, reduce the plant throughput. Small amounts of solvents will also be produced as byproduct. Essentially, these originate from gasoline dilution of crankcase oil, solvent contamination of industrial oils, and the effects of adsorbent treatment on waste oils. Table 34 lists the large number of products potentially available from a full-scale facility; these are given in approximate order of importance for the proposed design and include "waste" products.

Table 35 serves to indicate the products which can be recovered from various waste oil feedstocks. Although not comprehensive, this listing covers the waste oils of major interest.

Tables 36 through 42 give typical ASTM fuel oil, re-refined lube base, re-refined motor oil, virgin multi-grade motor oil, re-refined hydraulic oil and ASTM industrial solvent specifications. These and similar specifications will be used for product control at the WORRP facility. Note, however, that there is some latitude in such criteria (especially for fuel oils) depending on user requirements.

Sale of the proposed facility's products depends on the existence of a market. Table 14 gave data on the purchase of fuel oils by the State of Maryland in 1972. The indicated purchases of Nos. 5 and 6 fuel oils are sufficient to account for use of all of the full-scale process plant's product. Recognizing that many heating plants which burn No. 2 oil can be converted to No. 4 leads to the conclusion that this potential fuel oil market is much more than sufficient. The indicated storage capacity will, however, not offset the need for major storage at the process plant to any great extent. In the first place, the total storage volume is only about 25 percent of that required at the plant. Second, comparing the number of users and the deliveries per year to the indicated storage capacities implies that the State has very small tanks at most installations; such tankage would be more of a nuisance than a help in holding large quantities of bulk product fuel oil. The prices in Table 14 indicate that the similar figures used in the operating and maintenance cost estimates as well as general economic analyses are in line with the existing market.

Table 33. ESTIMATED STREAM-DAY PRODUCT FLOWS (1975)

Category	Stream-Day Flow (gal)	Yield (%)
Waste Crankcase Oil:		
Standard Processing -------	13,800	85
Adjusted Processing -------	7,000	71
Special Processing --------	3,800	76
TOTALS ----------------	24,600	68
Waste Industrial Oil:		
Standard Processing -------	9,300	87
Adjusted Processing -------	2,200	71
Special Processing --------	1,800	76
TOTALS ----------------	13,300	64
Waste Fuel Oil:		
Adjusted Processing -------	1,300	71
Special Processing --------	900	76
TOTALS ----------------	2,200	37
Waste Edible & Miscellaneous Oils:		
Special Processing --------	600	76
TOTALS ----------------	600	20
GRAND TOTALS ----------	40,700	62

Table 34. MES WASTE OIL DISPOSAL FACILITY -- PRODUCT SPECTRUM

1. Fuel Oils
2. Pre-treated Lube Oil Stocks
3. Pre-treated Diesel Oil Stocks
4. Re-refined Lube Oils
5. Re-refined Transformer Oils
6. Pre-treated Hydraulic Oil Stocks
7. Sterile, Non-toxic Ash
8. Carbon Dioxide & Water Vapor
9. Pre-treated Gear Oil Stocks
10. Pre-treated Turbine Oil Stocks
11. Re-refined Hydraulic Oils
12. Re-refined Cutting Oils
13. Re-refined Quench Oils
14. Process Fuels
15. $CaSO_4$, $CaCl_2$, Heavy Metal Ash
16. Solvents
17. Soap Stocks
18. Feed Additives
19. Process Feed For Others
20. Pre-treated Fatty Oil Stocks

Table 35. MES WASTE OIL DISPOSAL FACILITY -- SOURCE/PRODUCT MATRIX

	Products				
Source Material (Process Feed)	Fuel Oil	Pre-treated Lube Oil Stocks	Re-refined Lube Oils	Process Fuels (for use in plant)	Solvents
Automotive					
Crankcase Oils (Gas)	X	X	X		
Crankcase Oils (Diesel)	X	X	X		
Hydraulic Oils	X		X		
Station Separator Wastes	X			X	X
Aeromotive					
Slop Oils				X	X
Crankcase Oils	X	X	X		

Table 35 (Continued). MES WASTE OIL DISPOSAL FACILITY - SOURCE/PRODUCT MATRIX

Source Material (Process Feed)	Products					
	Fuel Oil	Pre-treated Lube Oil Stocks	Re-refined Lube Oils	Pre-treated Gear Oil Stocks	Pre-treated Turbine Oil Stocks	Re-refined Cutting Oils
Industrial						
Turbine Oils	X				X	
Cutting Oils	X					X
Emulsified Cutting Oils	X					
Gear Oils	X			X		
Hydraulic Oils	X	X	X			

Table 35 (Continued). MES WASTE OIL DISPOSAL FACILITY - SOURCE/PRODUCT MATRIX

	Products				
Source Material (Process Feed)	Fuel Oils	Re-refined Transformer Oils	Re-refined Quench Oils	Process Fuels (for use in plant)	Solvents
Industrial (Cont.)					
Quench Oils	X		X		
Transformer Oils	X	X			
Dewatered Bilge & Ballast Oils	X			X	
Paints & Varnishes	X			X	X
Tank Bottoms	X				
Spilled Oils (Other Than Crude)	X			X	X
Waste Process Oils	X			X	X

Table 35 (Continued). MES WASTE OIL DISPOSAL FACILITY - SOURCE/PRODUCT MATRIX

Source Material (Process Feed)	Products						
	Sterile, Non-toxic Ash	Carbon Dioxide & Water Vapor	$CaSO_4$, $CaCl_2$, Heavy Metal Ash	Soap Stocks	Feed Additives	Pre-treated Fatty Oil Stocks	Stored Material
Animal & Vegetable Oils							
Food Processing Oils				X	X	X	
Kitchen Separator Oils				X	X	X	
Wastewater Oils & Greases				X	X		
Other Waste Materials							
Cl, S & Heavy Metal-Free Oil	X	X					
Cl, S & Heavy Metal-Bearing Oils		X	X				X
Process BSW & Waste Residues	X	X	X				X
Oil-Bearing Waste Solids	X	X	X				X

Table 36. FUEL OIL SPECIFICATIONS (ASTM D-396)

Fuel Grade	Flash Point °F (Minimum)	Pour Point °F (Maximum)	Ash w/%	Viscosity SSU 100°F		Water and Sediment % Volume
				(Maximum)	(Minimum)	
4 Distillate	130	20	0.1	125	45	0.5
5 Residual	130	--	0.1	300	150	1.0
6 Residual	150	--	---	9,000	900	2.0

Table 37. TYPICAL RE-REFINED INDUSTRIAL LUBE BASE*

Viscosity Range Designation	Gravity (°API)	Flash Point (F)	Fire Point (F)	Viscosity SSU		Viscosity Index	Pour Point (F)	Color (ASTM)	Ash
				100°F	210°F				
150 @ 100 F	28.7	330	355	158	43.7	99	-55	4.5	0.00
300 @ 100 F	29.5	415	450	330	55.1	104	-25	4.0	0.00

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* Private Communication

Table 38. TYPICAL RE-REFINED MOTOR OIL SPECIFICATIONS*

Grade	10W-30 Heavy Duty	SAE 30 Non-Detergent	10W-40 Extra Heavy Duty
Gravity, °API	29.5	28.7	29.1
Flash, °F	420	450	395
Fire Point, °F	455	480	445
Viscosity:			
At 100 °F, SSU	300	540	322
At 210 °F, SSU	63.3	65.5	74.0
Viscosity Index	144	96	153
Pour Point, °F	-45	0	-45
Color (ASTM)	4.0	4.5	4.5
Ash, wt. %	1.00	0.00	1.31

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* Private communication.

Table 39. MULTIGRADE MOTOR OIL (10W-40)

(Meets API SD and SE Ford M2C-101-BB and GM 6041-M)*

Viscosity:	
100 °F	498 SSU
210 °F	77 SSU
Viscosity Index	154
Flash Point	440 °F
Gravity	29.5° API
Pour Point	-30 °F

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* Humble Oil and Refining Company Data Sheet DG-2A.

Table 40. COMMERCIAL AUTOMOTIVE ENGINE OIL**

SAE Number	30
Gravity	27.7° API
Specific Gravity	0.889
Pour Point	-10 °F Max.
Flash Point	415 °F Min.
Viscosity:	
0 °F	9,600
100 °F	327
210 °F	55
Viscosity Index	95
Color (ASTM)	6.5
Sulfated Ash	1.0 wt. % max.
Total Base Number	9 (Mobil Method 308)

** Mobile Product Data Sheet #2-35-012. Gasoline or Diesel Service.

Table 41. TYPICAL RE-REFINED HYDRAULIC OILS*

Grade	Regular Light	Regular Medium	Regular Heavy Duty
Gravity, °API	30.8	30.0	28.5
Flash Point, °F	380	400	415
Fire Point, °F	430	450	460
Viscosity @ 100F, SSU	160	250	500
Viscosity Index	100	100	95
Compounding	2500 Hour Oxidation Test D-943		
Vickers Pump Test	Pass	Pass	Pass
Rust Test	Pass	Pass	Pass
Foam Test	Pass	Pass	Pass

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* Private communication.

Table 42. TYPICAL INDUSTRIAL SOLVENT SPECIFICATIONS (ASTM-D-965)

APPEARANCE	Clear and free of suspended matter and water.
MINIMUM FLASH POINT	125°F
CORROSION (Copper Strip)	No Corrosion of clean copper in 30 minutes at boiling point of solvent.
DISTILLATION:	
Initial Boiling Point	340°F
95% Volume Boiling Point	460°F
Maximum End Point	485°F
ACIDITY OF DISTILLATION RESIDUE	Neutral

SECTION X

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Waste Oil Recovery Practices, State-of-the-Art, prepared by Environmental Quality Systems, Inc. for the Maryland Environmental Service and the Environmental Protection Agency, 1972.

Waste Oil Reprocessing, Project No. 72-5, ESSO Research and Engineering Company, January 1973.

Water Resources Regulation 4.02, "Prevention of Oil Pollution".

APPENDIX A

General Criteria for Selection of Unit Processes

Selection of a particular approach must be based on the principle of "Best Practice" which must, in turn, consider:

1. Necessity -- If there is no viable alternative to a particular unit process, it must be included in a re-refining scheme. Of the unit processes being considered, only flash distillation and filtration are in essence necessary; each other can, in principle, be replaced by an alternate unit process.

2. Proven Performance -- Certain of the unit processes have been amply demonstrated in actual re-refining operations, and this was considered to be a positive attribute. Settling, flash distillation, sulfuric acid treatment, solvent extraction, adsorbent treatment, and filtration possess this attribute in a general sense.

3. Capital Cost -- Low initial investment is desirable for any unit process. For example, settling, flash distillation, chemical treatment, sulfuric acid treatment, solvent extraction, and adsorbent treatment involve lower capital cost than fractionation.

4. Operating Costs -- Low operating costs are also to be desired. Settling, flash distillation, chemical treatment, sulfuric acid treatment, vacuum distillation, solvent extraction, and adsorbent treatment were compared in this regard.

5. Commercial Availability -- Equipment and techniques should preferably be available commercially (off-the-shelf) in order to facilitate rapid implementation of a waste oil re-refining program. Of the unit processes considered, only hydrofining has no commercial source with regard to re-refining waste oils.

6. Process Yield -- Large quantities or proportions of wastes or residues from a unit process are undesirable. Only sulfuric acid treatment, filtration, and vacuum fractionation present significant difficulties in this regard.

7. Product Purity -- Considered in and of itself, a unit process should potentially yield a product which requires little or no further treatment. In a general sense, settling and flash distillation cannot usually meet this criteria, while centrifugation and chemical treatment are somewhat unreliable (i.e., may or may not be adjustable to give a relatively pure product depending on a number of critical variables).

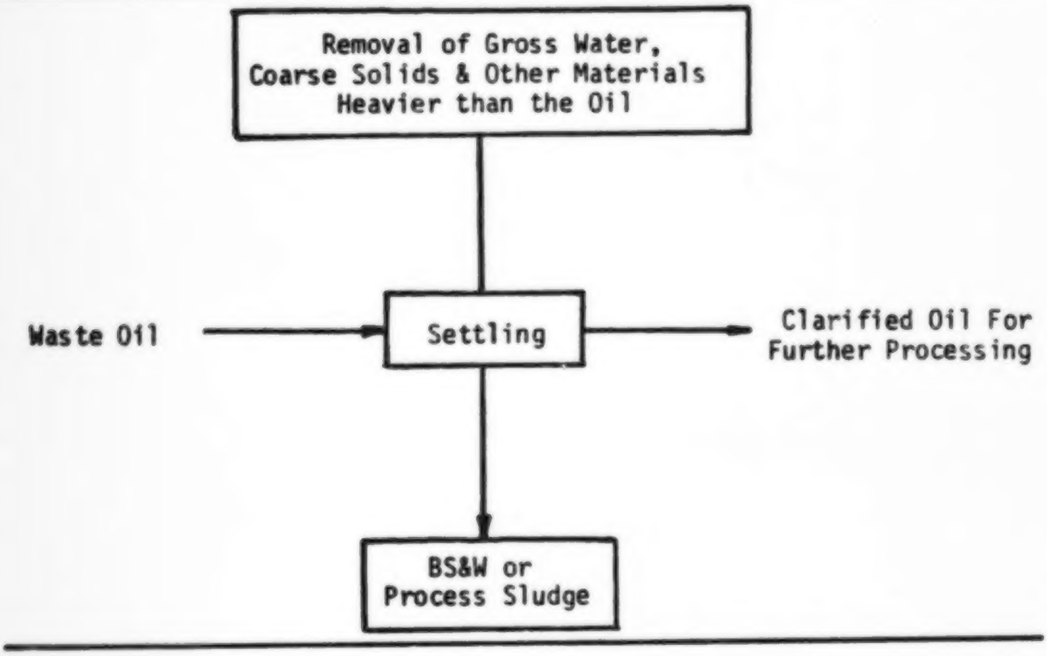
8. Wide Applicability -- Capability of re-refining many types of waste oils is a desirable quality for not only a comprehensive treatment facility but also individual unit processes. Centrifugation, sulfuric acid treatment, vacuum distillation and hydrofining are generally highly specific in their ability to successfully process waste oils and, therefore, are deficient with regard to the criteria of wide application.

9. Energy Requirements -- All other factors being equal, a unit process should require a low power input. Settling, chemical treatment, sulfuric acid treatment, adsorbent treatment, and filtration generally comply with this design requirement, while the other unit processes necessitate a significant power service. In a general sense, this is nothing more than a requirement for a minimum energy demand by a facility.

APPENDIX B

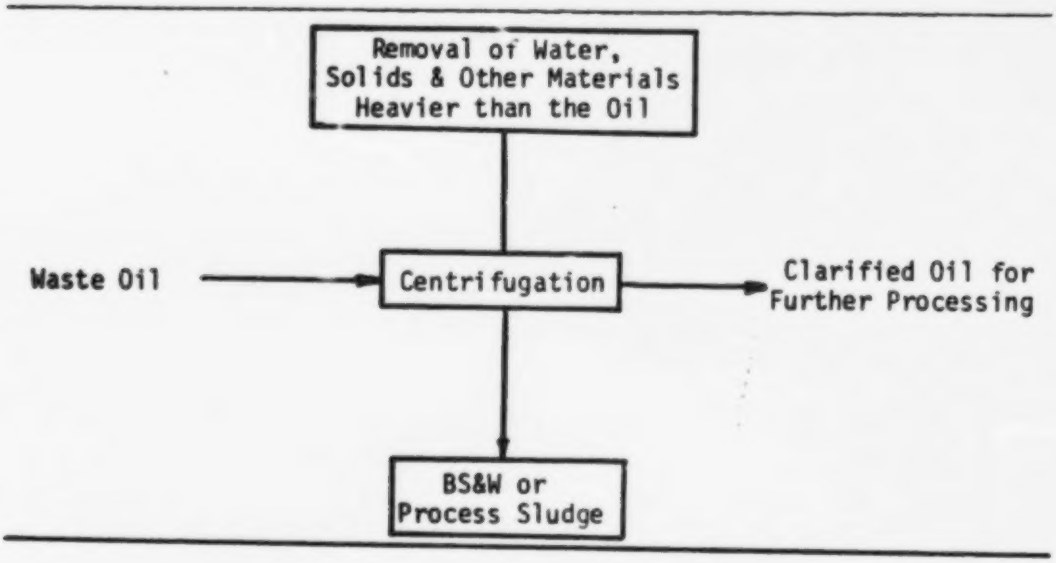
Diagrammatic Evaluation of Various Unit Processes

Figure 11. EVALUATION OF SETTLING


Removal of Gross Water, Coarse Solids & Other Materials Heavier than the Oil
Waste Oil
Settling
Clarified Oil For Further Processing
BS&W or Process Sludge

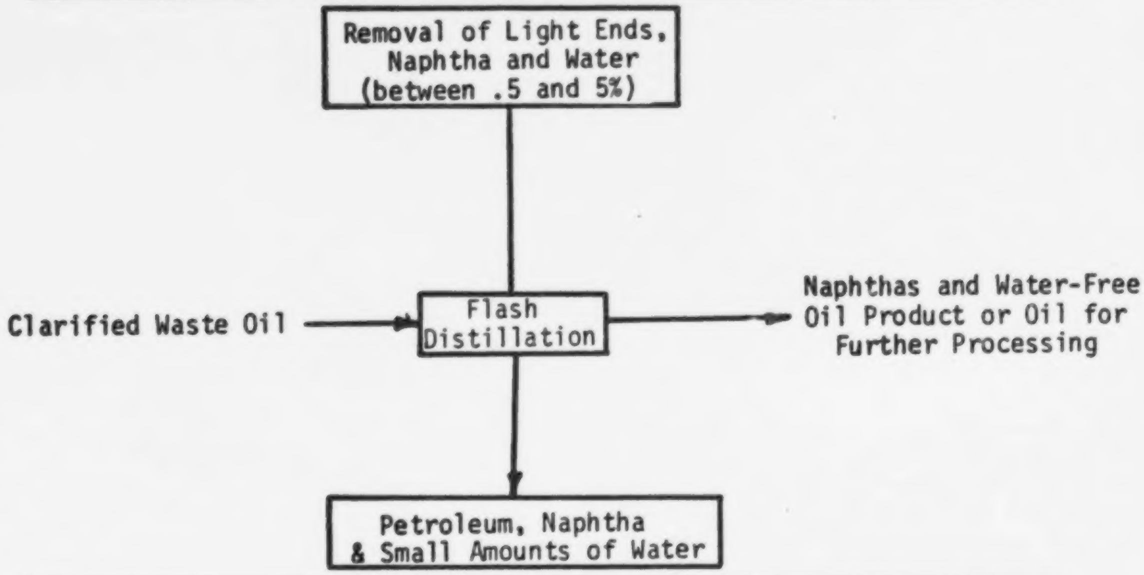
Advantages	Disadvantages
1. Standard unit operation.	1. Ineffective for very small particles or neutral density materials.
2. Uses otherwise necessary tankage for processing.	2. Can require long settling times or heating to be effective.
3. Residence times easily adjustable.	
4. Low capital & operating costs compared to filtration and stripping.	
5. Performance demonstrated.	
6. Implementation possible in near future.	

Figure 12. EVALUATION OF CENTRIFUGATION


Removal of Water, Solids & Other Materials Heavier than the Oil
Waste Oil
Centrifugation
Clarified Oil for Further Processing
BS&W or Process Sludge

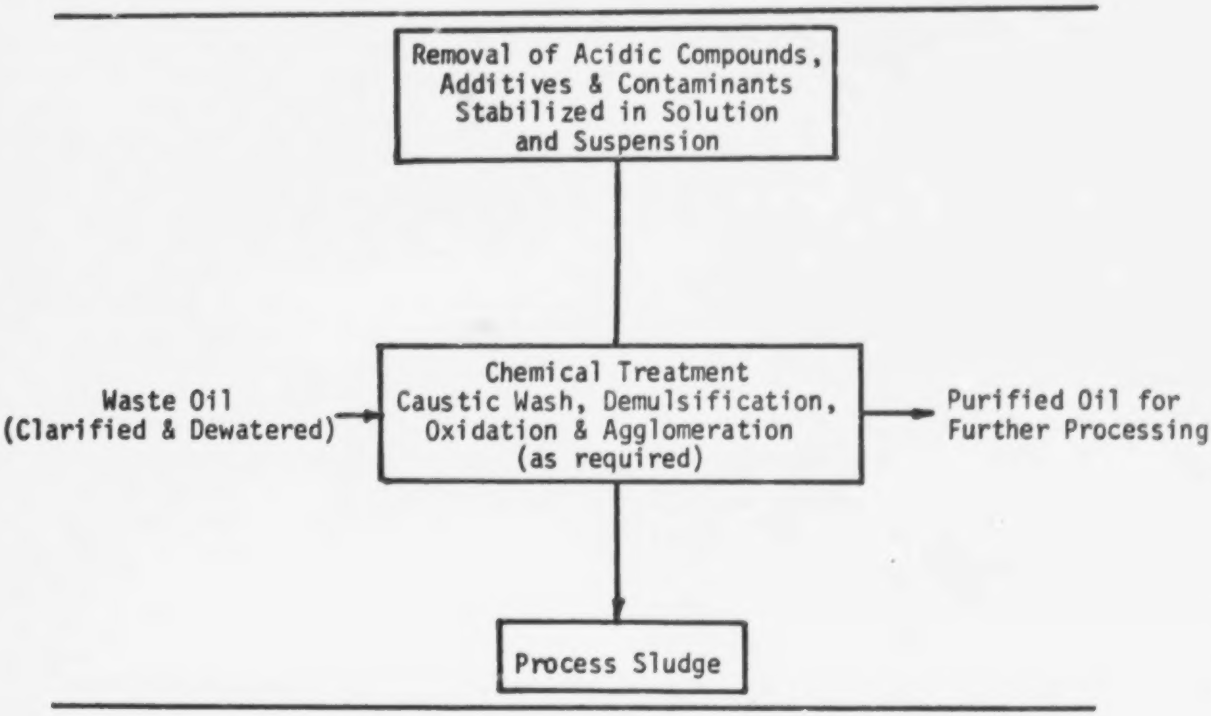
Advantages	Disadvantages
1. Already in limited use.	1. Higher capital & operating costs than settling and filtration.
2. Can remove small solid particles & water droplets from oil.	2. Performance not well demonstrated.
3. Requires less land area than settling tanks.	3. Requires heating or dilution of oil.
4. Rapid processing rate compared to settling.	4. Additional unit operation as opposed to use of storage tanks for settling.
	5. Throughputs and residence times not adjustable over wide ranges of feed characteristics.
	6. Not applicable to multi-phase separation.
	7. Will require additional testing & evaluation for application to wide range of feed.

Figure 13. EVALUATION OF FLASH DISTILLATION


Removal of Light Ends, Naphtha and Water (between .5 and 5%)
Clarified Waste Oil
Flash Distillation
Naphthas and Water-Free Oil Product or Oil for Further Processing
Petroleum, Naphtha & Small Amounts of Water

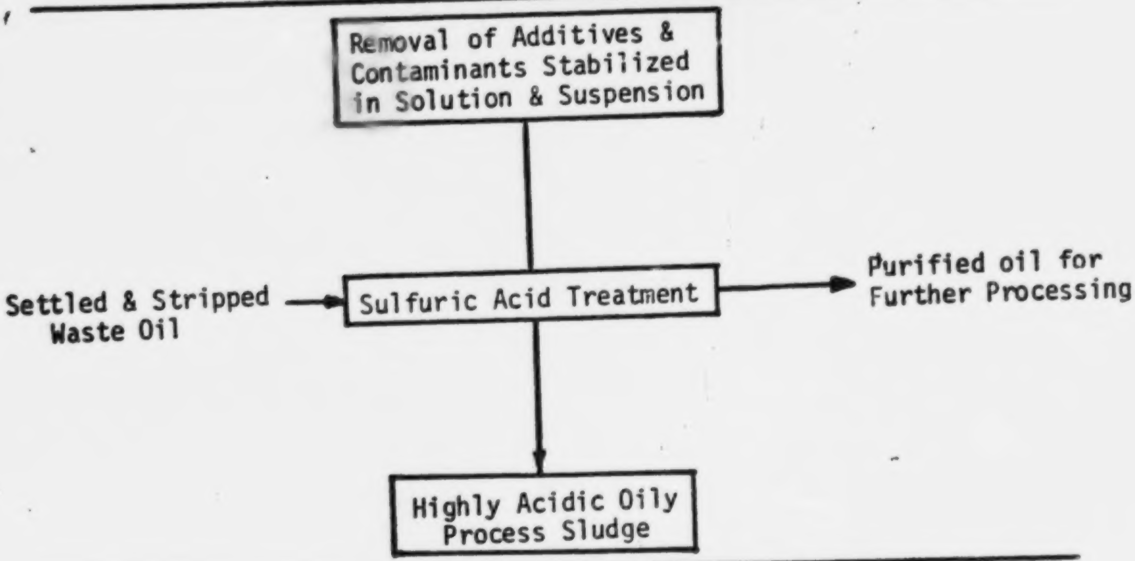
Advantages	Disadvantages
1. Demonstrated unit operation.	1. Direct fired heaters for waste oil service require special design.
2. Uses conventional hardware.	
3. Capital & operating costs lower than solvent extraction or adsorption purification.	2. Such heaters are more costly than comparable refinery facilities.
4. Implementation possible in near future.	3. Caking occurs on furnace tubes and in the still and requires frequent maintenance.

Figure 14. EVALUATION OF CHEMICAL TREATMENT


Removal of Acidic Compounds, Additives & Contaminants Stabilized in Solution and Suspension
Waste Oil (Clarified & Dewatered)
Chemical Treatment Caustic Wash, Demulsification, Oxidation & Agglomeration (as required)
Purified Oil for Further Processing
Process Sludge

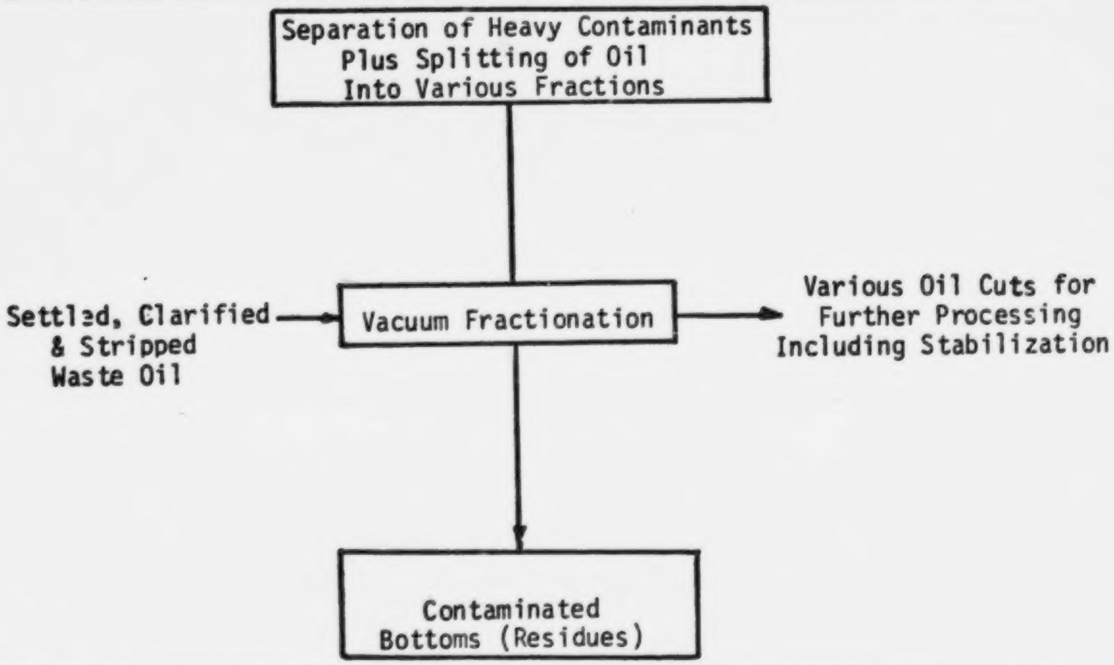
Advantages	Disadvantages
1. Can be performed in same facilities with basic settling operation.	1. Process control is complex.
2. Implementation possible in near future.	2. Performance not demonstrated.
3. Minimizes sludge production by use of small or trace amounts of reagents.	3. Chemical usage is dependent on feed oil characteristics.
4. Reagents are commercially available.	
5. More applicable to wider range of feed characteristics than sulfuric acid treatment.	
6. Capital & operating costs lower than solvent extraction.	

Figure 15. EVALUATION OF SULFURIC ACID TREATMENT


Removal of Additives & Contaminants Stabilized in Solution & Suspension
Settled & Stripped Waste Oil
Sulfuric Acid Treatment
Purified oil for Further Processing
Highly Acidic Oily Process Sludge

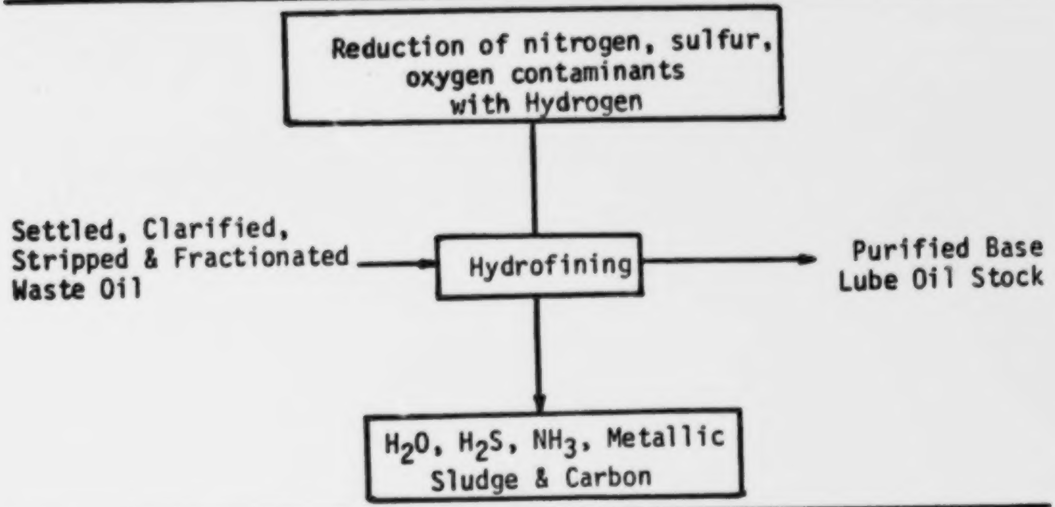
Advantages	Disadvantages
1. Demonstrated performance.	1. Application limited to crankcase or similar oils.
2. Implementation possible in near future.	2. Produces large quantities of highly acid waste sludges.
3. Operation of process is straightforward and standardized.	3. Requires sludge disposal program more costly than solvent extraction and distillation process residues.
4. Capital and operating costs lower than combination of solvent extraction and fractional distillation.	

Figure 16. EVALUATION OF VACUUM FRACTIONATION


Separation of Heavy Contaminants Plus Splitting of Oil Into Various Fractions
Settled, Clarified & Stripped Waste Oil
Vacuum Fractionation
Various Oil Cuts for Further Processing Including Stabilization
Contaminated Bottoms (Residues)

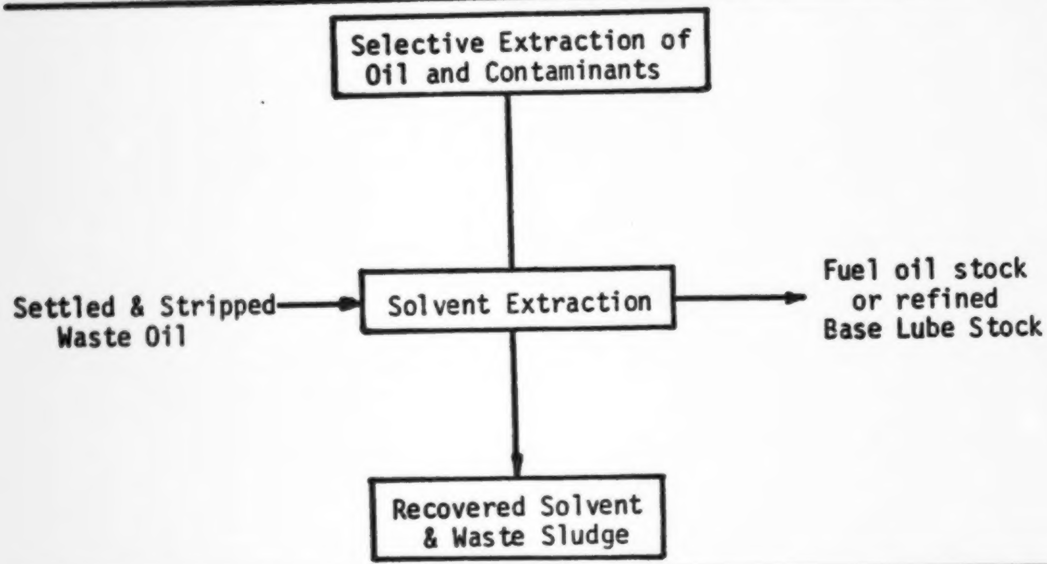
Advantages	Disadvantages
1. Uses available hardware.	1. Produces contaminated bottoms which must be disposed of.
2. Moderate capital and operating costs compared to solvent extraction.	2. High temperature operation required.
3. Capable of producing a range of products.	3. Loss of potential products in bottoms.
4. Implementation possible in the near future.	4. Direct fired heater design and operating problems as with flash distillation.
	5. Near term application limited to additive and heavy metal-free feed, and feed free of azeotropes.

Figure 17. EVALUATION OF HYDROFINING


Reduction of nitrogen, sulfur, oxygen contaminants with Hydrogen
Settled, Clarified, Stripped & Fractionated Waste Oil
Hydrofining
Purified Base Lube Oil Stock
H_2O, H_2S, NH_3, Metallic Sludge & Carbon

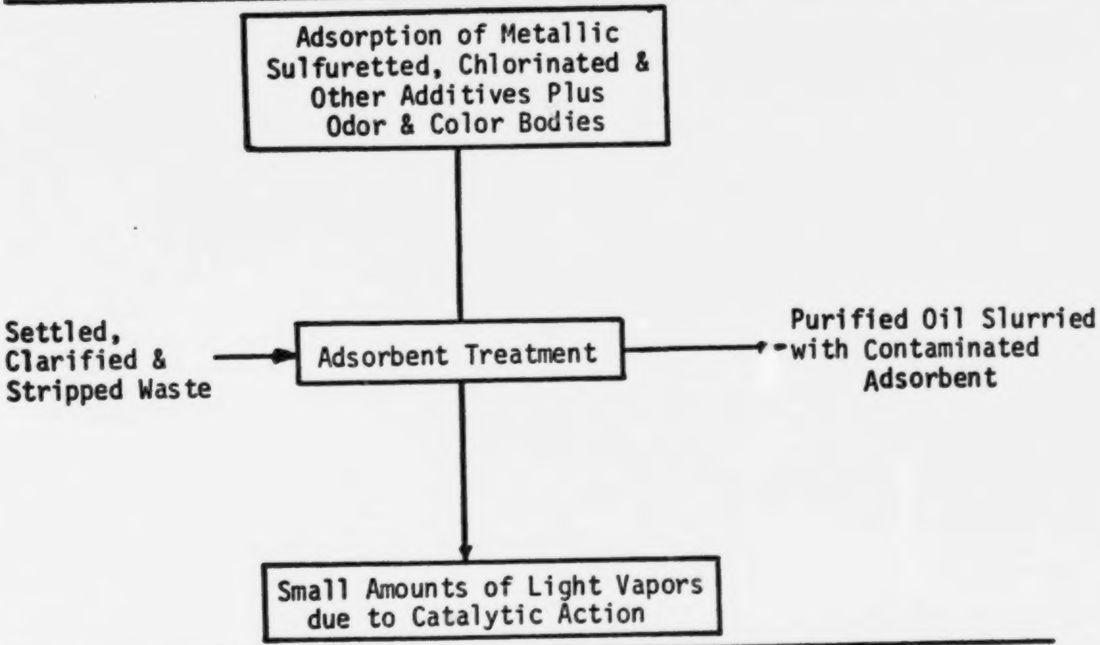
Advantages	Disadvantages
1. Potential for production of a highly purified base oil stock.	1. Unproven commercial performance for waste oils.
2 Potential of small amounts of process residues	2. Requires special cobalt-molybdenum oxide catalyst.
	3. Catalyst is poisoned by carbon monoxide and contaminants such as chlorine and heavy metals.
	4. May require large amounts of hydrogen.
	5. High pressure/high temperature process.
	6. High capital and operating costs for the basic hydrofining equipment.
	7. Necessary hydrogen plant also would involve additional capital and operating costs.
	8. Implementation is possible only after additional development.
	9. Process operation dependent on the nature of the feed oil.

Figure 18. EVALUATION OF SOLVENT EXTRACTION


Selective Extraction of Oil and Contaminants
Settled & Stripped Waste Oil
Solvent Extraction
Fuel oil stock or refined Base Lube Stock
Recovered Solvent & Waste Sludge

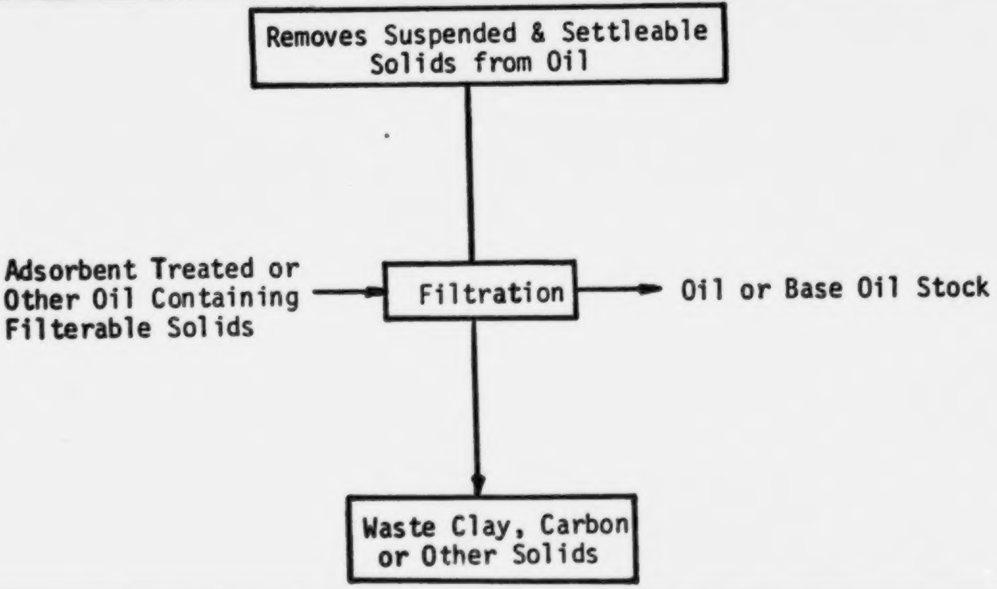
Advantages	Disadvantages
1. Demonstrated performance on both full and bench scales (limited on waste oils).	1. Requires additional stripping operations for product, sludge and solvent recovery.
2. Solvent can be selected to suit the feed stock quality.	2. Requires sophisticated process and quality control.
3. Solvent is recovered for reuse.	3. Can require long settling times in cases where feed and solvent density values are similar.
4. Implementation possible in near future.	
5. Concentrates contaminants.	
6. Uses conventional hardware	
7. Lower capital and operating costs than adsorptive purification.	
8. Some solvents could be produced by the plant.	
9. Can be used to break emulsions.	

Figure 19. EVALUATION OF ADSORBENT TREATMENT


Adsorption of Metallic Sulfuretted, Chlorinated & Other Additives Plus Odor & Color Bodies
Settled, Clarified & Stripped Waste
Adsorbent Treatment
Purified Oil Slurried with Contaminated Adsorbent
Small Amounts of Light Vapors due to Catalytic Action

Advantages	Disadvantages
1. Demonstrated performance in full scale operations (clay).	1. Requires pretreatment and subsequent filtration.
2. Lower capital & operating costs than hydrofining.	2. Adsorbent requires regeneration and/or disposal.
3. Uses conventional hardware.	3. Heater problems similar to stripping.
4. High performance as a finish step to remove trace amounts of contaminants.	
5. Implementation possible in the near future.	

Figure 20. EVALUATION OF FILTRATION


Removes Suspended & Settleable Solids from Oil
Adsorbent Treated or Other Oil Containing Filterable Solids
Filtration
Oil or Base Oil Stock
Waste Clay, Carbon or Other Solids

Advantages	Disadvantages
1. Demonstrated performance in full scale operations.	1. Adsorbent requires regeneration and/or disposal.
2. Uses conventional hardware.	2. Not applicable to colloidal suspensions and some emulsions.
3. Implementation possible in near future.	
4. Applicable to a wide range of feed quality.	
5. Process operation and control is straightforward.	
6. Capital costs lower than centrifugation.	

Table 43. PROCESS ALTERNATIVES RATING MATRIX

PROCESS	Necessity	Proven Performance	Capital Cost	Operating Cost	Commercial Availability	Product Yield	Product Purity	Wide Applicability	Energy Requirements
Settling	-	+	+	+	+	+	-	+	+
Centrifugation	-	-	-	-	+	+	0	-	-
Flash Distillation	+	+	+	+	+	+	-	+	-
Chemical Treatment	-	-	+	+	+	+	0	+	+
Sulfuric Acid Treatment	-	+	+	+	+	-	+	-	+
Vacuum Distillation	-	+	-	+	0	-	+	-	-
Hydrofining	-	-	-	-	-	+	+	-	-
Solvent Extraction	-	+	-	0	+	0	0	+	-
Adsorbent Treatment	-	+	+	+	+	+	+	+	+
Filtration	+	+	-	-	+	+	+	+	+

Table 44. ULTIMATE DISPOSAL PROCESS RATING MATRIX

PROCESS	Environmental Impact	Simplicity	Steady-State	Public Acceptance	Industrial Acceptance	Capital Cost	Operating Cost	Reliability	Risk	Legal
Incinerate & Recover	+	-	+	+	+	-	+	+	+	-
Store Waste	-	+	-	0	0	-	+	0	+	-
Purchase Service	+	0	+	0	0	+	-	0	-	-
Incinerate & Landfill	-	-	+	-	+	-	+	-	-	-
Landfill (Private)	-	+	+	-	+	0	-	-	-	-
Landfill (MES)	-	+	+	-	+	-	+	-	+	-

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